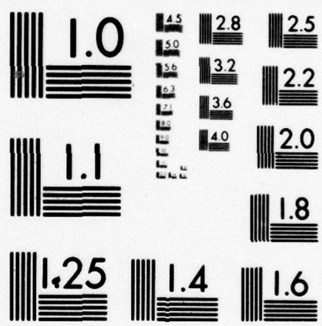
AD-A077 674 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL--ETC F/G 8/8
ANALYSIS OF POTENTIAL FLOOD DAMAGE AT WRIGHT-PATTERSON AIR FORC--ETC(U)
SEP 79 P F QUINN , J W WIMBERLEY
UNCLASSIFIED AFIT-LSSR-24-79A NL

1 OF 2
ADA 077674



MICROCOPY RESOLUTION TEST CHART

6

ANALYSIS OF POTENTIAL FLOOD DAMAGE AT WRIGHT-PATTERSON AIR FORCE BASE.

10
Patrick F. Quinn, Captain, USAF
James W. Wimberley, Captain, USAF

14 AFIT-LSSR-24-79A

9 Master's thesis,

11 Sep 79

12 168

USAF SCN 75-20B AFIT Control Number LSSR 24-79A

AFIT RESEARCH ASSESSMENT

The purpose of this questionnaire is to determine the potential for current and future applications of AFIT thesis research. Please return completed questionnaires to: AFIT/ LSH (Thesis Feedback), Wright-Patterson AFB, Ohio 45433.

1. Did this research contribute to a current Air Force project?

   a. Yes b. No

2. Do you believe this research topic is significant enough that it would have been researched (or contracted) by your organization or another agency if AFIT had not researched it?

   a. Yes b. No

3. The benefits of AFIT research can often be expressed by the equivalent value that your agency received by virtue of AFIT performing the research. Can you estimate what this research would have cost if it had been accomplished under contract or if it had been done in-house in terms of manpower and/or dollars?

   a. Man-years ________ $ ________ (Contract).

   b. Man-years ________ $ ________ (In-house).

4. Often it is not possible to attach equivalent dollar values to research, although the results of the research may, in fact, be important. Whether or not you were able to establish an equivalent value for this research (3 above), what is your estimate of its significance?

   a. Highly Significant b. Significant c. Slightly Significant d. Of No Significance

5. Comments:

________________________ ________________________
Name and Grade Position

________________________ ________________________
Organization Location

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

BUSINESS REPLY MAIL

FIRST CLASS PERMIT NO. 73236 WASHINGTON D.C.

POSTAGE WILL BE PAID BY ADDRESSEE

AFIT/LSH (Thesis Feedback)
Wright-Patterson AFB OH 45433

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER LSSR 24-79A	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ANALYSIS OF POTENTIAL FLOOD DAMAGE AT WRIGHT-PATTERSON AIR FORCE BASE		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Patrick F. Quinn, Captain, USAF James W. Wimberley, Captain, USAF		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS School of Systems and Logistics Air Force Institute of Technology WPAFB, OH		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Department of Communication and Humanities AFIT/LSH, WPADB, OH 45433		12. REPORT DATE September 1979 13. NUMBER OF PAGES 153
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

JOSEPH P. HIPPS, Major, USAF
Director of Information

18 SEP 1979

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

flood damage
floodplain
flood probability
Wright-Patterson Air Force Base
Huffman Dam
Mad River

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Thesis Chairman: Todd Stewart, Captain, USAF

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

ABSTRACT:

Flooding of areas "A" and "C" of Wright-Patterson Air Force Base has always been a conspicuous threat manifested by the presence of Huffman Dam at the south end of this portion of the base complex. The problem of assessing the threat has been previously addressed by base agencies and the U.S. Army Corps of Engineers with no decisive conclusions. In this analysis an attempt is made to evaluate methods of flood probability determination and select the most appropriate for establishing flood elevation probabilities within the Huffman Dam Basin. Regression analysis of past flooding provided the most reliable model for prediction. The attempt to measure and predict potential economic damage, however, could not be fitted to a reliable model due to variances in building construction and the lack of an extensive and consistent data base of flood damage in the United States. The analysis of methods for predicting damage did produce a model for establishing limits of damage probability in any period of years. This model may be improved upon with an expanded data base of surveys of flood damage from past and future events in other locations.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

LSSR 24-79A

ANALYSIS OF POTENTIAL FLOOD DAMAGE AT WRIGHT-PATTERSON AIR FORCE BASE

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Facilities Management

By

Patrick F. Quinn, BSE, PE
Captain, USAF

James W. Wimberley, BArch
Captain, USAF

September 1979

Approved for public release;
distribution unlimited

This thesis, written by

Captain Patrick F. Quinn

and

Captain James W. Wimberley

has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN FACILITIES MANAGEMENT

Date: 7 September 1979

COMMITTEE CHAIRMAN

ACKNOWLEDGEMENT

The authors wish to express their appreciation to Captain E. Graves, who provided much of the research and cultivated data sources which led to the conclusions of this study. Particular gratitude and some astonished awe is owed to the patience of Captain Todd Stewart and Mrs. Linda Pearson, which was exercised throughout this protracted labor.

TABLE OF CONTENTS

Chapter	Page

LIST OF TABLES

LIST OF FIGURES

Figure | Page

CHAPTER I

INTRODUCTION

Background

The possibility of flooding in the present Wright-Patterson Air Force Base area has been a matter of concern since the severe floods of Dayton, Ohio, in 1898 and 1913. The Miami River Valley is made up of three river systems which converge at Dayton: the Stillwater River, the Miami River, and the Mad River. This region is shown in Figure 1. The greatest flood disaster ever recorded in the Miami Valley occurred in March 1913. As a result of that disaster, which cost 400 lives and 100 million dollars in damages, the Miami Conservancy District (MCD) was formed in 1915 (18:13). To protect Dayton from the recurrence of a similar flood disaster, the MCD implemented a plan to construct five earthen dams including Huffman Dam (18:85).

Huffman Dam forms a retention basin of the valley above it. The dam is constructed mainly of earth placed across a narrow (3,340 ft.) section of the Mad River Valley, and is fifty-eight feet high from river bed to spillway crest. A segment of its structure is a portland cement concrete section containing a spillway directly above three conduits. The spillway crest is at 835 feet

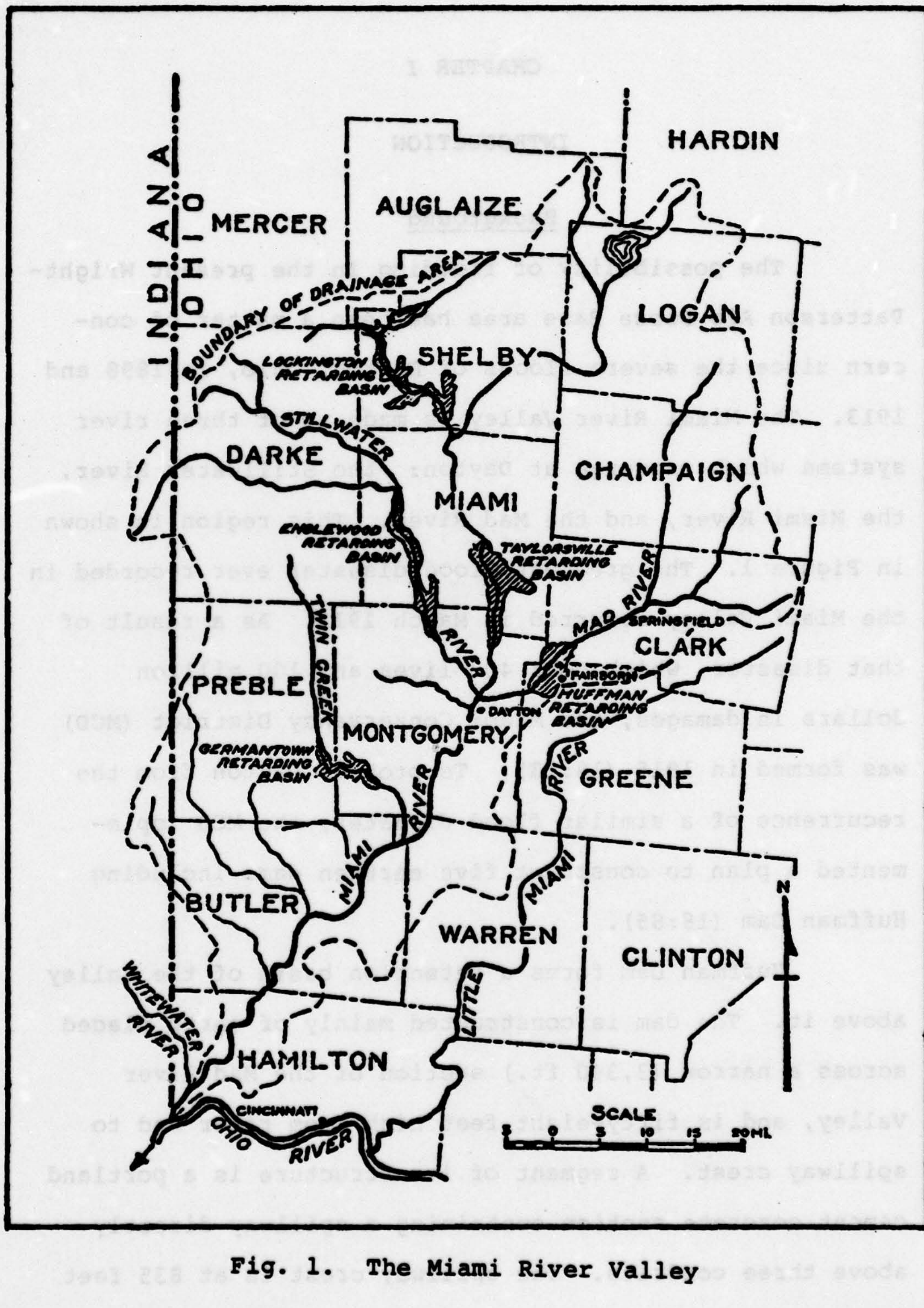


Fig. 1. The Miami River Valley

above mean sea level (MSL). The conduits are openings in the dam which allow the river to flow unimpeded at normal quantities of flow. If the river were to flow at a sufficient rate to otherwise cause flooding downstream, the conduits would restrict flow by their relatively small size, causing water to pond behind the dam. Operation of the dam is completely passive, controlled only by the flow of the river and the fixed size of the conduits (18:387-390). A simplified cut-away diagram of the dam is shown in Figure 2.

With the construction of Huffman Dam, a 9,180 acre retarding basin[1] was created (33:328).

> Huffman Dam was designed to allow normal water flow to pass while flood waters are held back. Excess water is held above the dam only long enough to drain safely away. The design stops flooding [in Dayton] while preserving the character of the valley above the dam [11].

The preceding statement by the Dayton-Montgomery County Park Service refers to the fact that, under usual conditions, the valley above the dam is unaffected by the presence of the dam. However, a subtle change has been made in the character of the valley, in that anyone planning to locate facilities in the retarding basin must be aware that waters will be held back in the area when a flood event occurs. The MCD records a flood event when

---

[1]Retarding basin: maximum area behind the dam in which water is stored temporarily to reduce peak flows below the dam.

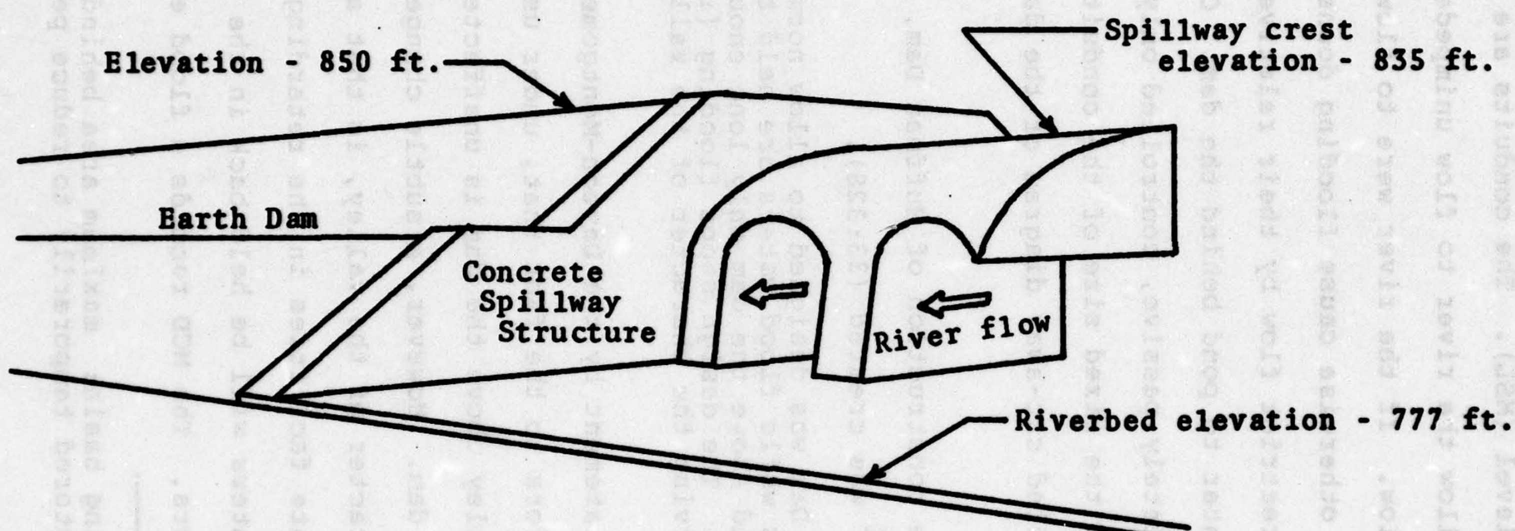


Fig. 2. Simplified Cut-Away Diagram of Huffman Dam at Spillway

the elevation of high water at the inlet of the dam reaches or exceeds 788 feet above mean sea level (21). The 788 feet MSL elevations correspond approximately to the surface elevation of the Mad River at "bank full" conditions.

Since the construction of Huffman Dam,from 1922 through 1977, there have been ninety floods exceeding 788 feet MSL. A histogram of the occurrences is shown in Figure 3. As recently as 1959 the water elevation reached 809 feet MSL, which inundated more than 50 percent of the area of Wright-Patterson Air Force Base above the dam (16).

In 1922, the MCD sold over 3,700 acres of the Huffman Dam retarding basin to the Dayton Air Service Incorporated Committee (19:427). Two years later the Committee presented that land to the U.S. government (19:427). The land comprises roughly the Areas "A" and "C" of today's Wright-Patterson Air Force Base (WPAFB) as shown in Figure 4.

Of importance in the deed are the reservations, restrictions, conditions, and limitations in which the parties to the transaction recognized the possibility of flooding in the area. Those stipulations, which will be referred to simply as restrictions, stated the following (31:12):

1. The MCD has the right (a) to back the waters of Mad River upon and over the premises up to an elevation

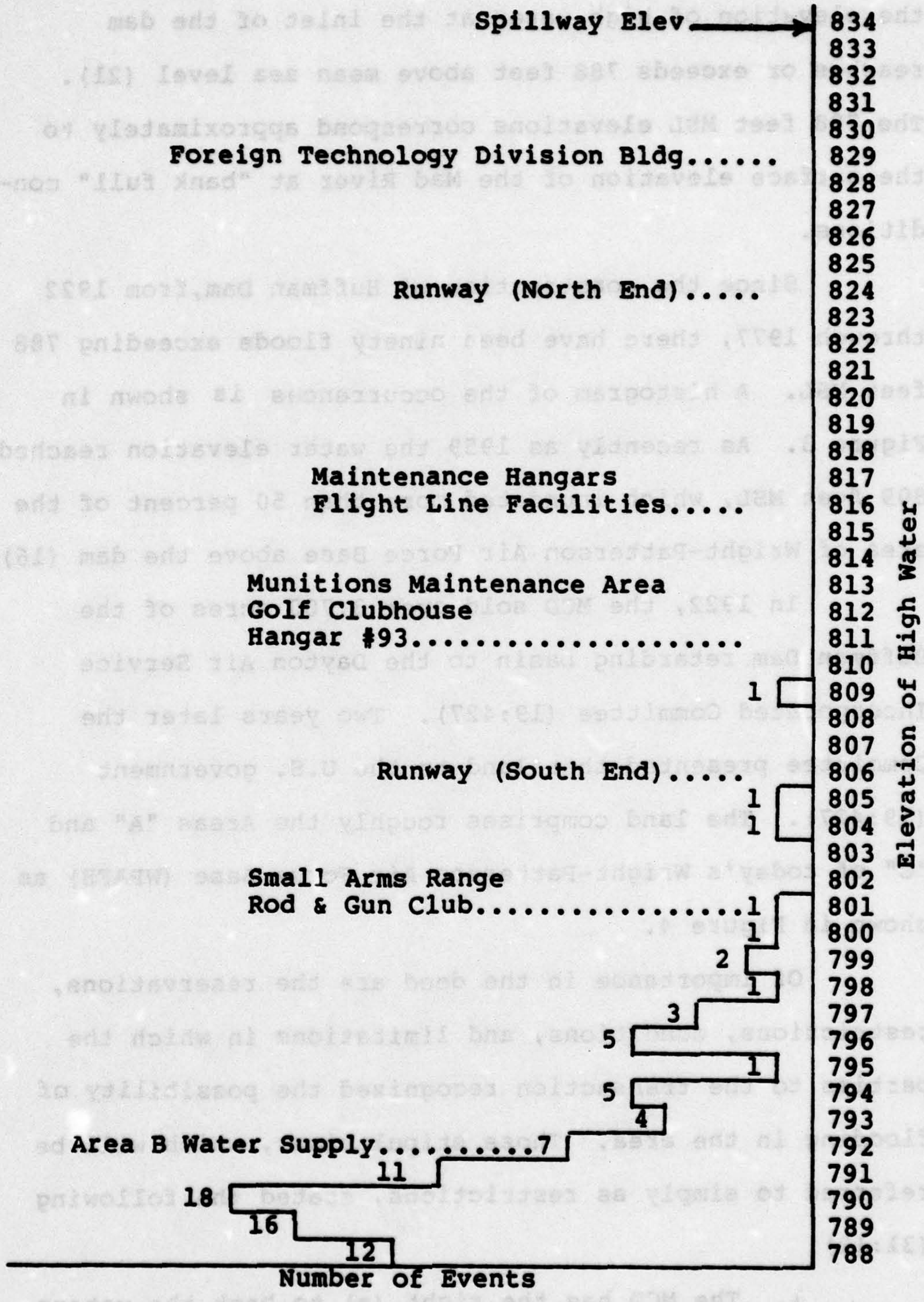


Fig. 3. History of Flooding, Huffman Basin
1922-1977 (21)

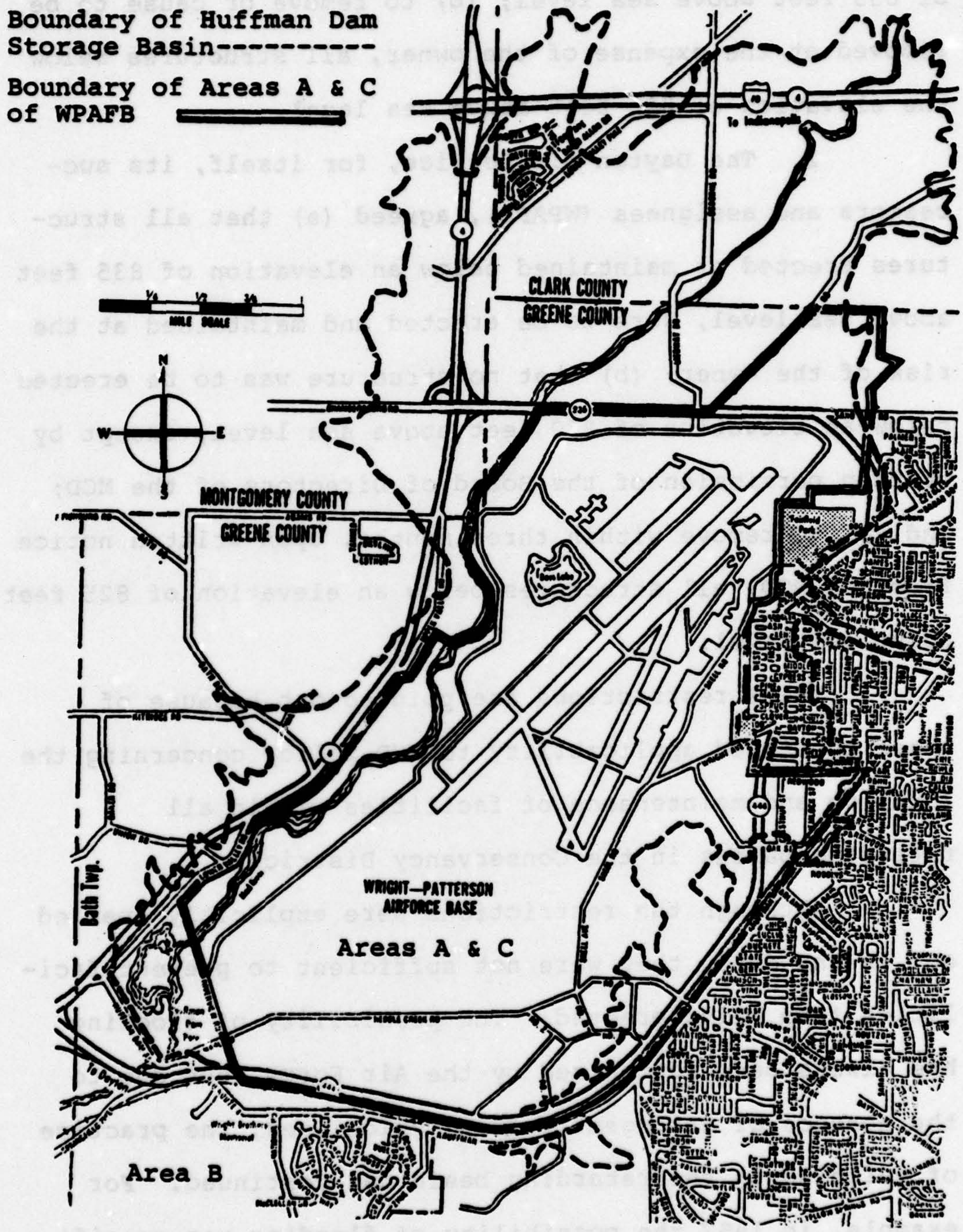


Fig. 4. Boundaries of the Huffman Dam Retarding Basin and Areas "A" and "C" of Wright-Patterson Air Force Base

of 835 feet above sea level; (b) to remove or cause to be removed at the expense of the owner, all structures below the elevation of 825 feet above sea level.

2. The Dayton Air Service, for itself, its successors and assignees (WPAFB), agreed (a) that all structures erected or maintained below an elevation of 835 feet above sea level, were to be erected and maintained at the risk of the owner; (b) that no structure was to be erected below an elevation of 830 feet above sea level, except by written permission of the Board of Directors of the MCD; and (c) to remove within three months, upon written notice from the MCD, all structures below an elevation of 825 feet above sea level.

These restrictions are pointed out because of their continued applicability to MCD policy concerning the location and maintenance of facilities within all retarding basins in the Conservancy District.

Although the restrictions were explicitly spelled out in the deed, they were not sufficient to prevent facilities from being erected. The possibility of flooding has always been recognized by the Air Force, but due to the absence of stringent federal guidelines, the practice of building in the retarding basin has continued. For example, in 1952 the possibility of flooding was specifically addressed in a Base Plan Board Meeting (34). However, the flood interval predictions and the legal and

economic implications to facilities located in flood prone areas were too uncertain at that time to draw a conclusion to support or prevent construction.

With the passage of Executive Order (EO) 11988, May 24, 1977, a new precedent in flood plain[2] management was fixed (30). EO 11988 implements the policies promulgated in the National Environmental Policy Act of 1969, the National Flood Insurance Act of 1968, and the Flood Disaster Protection Act of 1973. The crux of this order called for a centralization and simplification of the various ways different organizations were administering flood plain management. Furthermore, it simultaneously applied to both the private and public sectors. EO 11988 for the first time, tasked each federal agency with the responsibility to:

> . . . provide leadership and . . . take action to reduce the risk of flood loss, to minimize the impact of floods on human safety, health and welfare, and to restore and preserve the natural and beneficial values served by flood plains . . . .
>
> In carrying out the activities . . . each agency has a responsibility to evaluate the potential effects of any actions it may take in a flood plain; . . . [and] to ensure that its planning programs and budget requests reflect consideration of flood hazards and flood plain management . . . [30:2].

---

[2]Flood plain: The lowlands and relatively flat areas adjoining inland and coastal waters, including at a minimum, that area subject to a 1 percent or greater chance of flooding in any given year [30:5].

WPAFB becomes directly involved with the required consideration of flood hazards because of the demonstrated potential for flooding in the retarding basin.

Problem Statement

It has been shown that a possibility of flooding exists in the Huffman Dam retarding basin, and that WPAFB has a responsibility to consider the potential flood damage. The 2750th Civil Engineering Squadron at WPAFB has not been able to obtain a definitive analysis of flood probabilities nor a detailed analysis and assessment of the flood hazard within the Huffman Dam retarding basin (9). There is a need to assess the likelihood of flooding and the extent of possible damages from flooding of installation facilities. The likelihood of flooding is stated in terms of the probabilities of various elevations being exceeded within the retarding basin in a given period of time. The extent of possible damage is stated in terms of "uniform annual expected damages," which are costs associated with certain flood elevations multiplied by the probability that those elevations will be exceeded in any year (8:141).

Justification

Section 2.(c) of EO 11988 calls for federal agencies such as WPAFB to:

> Take flood plain management into account when formulating or evaluating any water and land use plans

and . . . [to] require land and water resources use appropriate to the degree of hazard involved [30:2].

Planning of facilities utilization and construction on WPAFB requires consideration of the effects of possible flooding for reasons of economy, safety, and continuance of operations.

For any planned project there is an economic break even point for flood protection (14:578-9). If the likelihood or seriousness of flooding is underestimated, there is a possibility of sustaining greater losses than are acceptable. At the other end of the scale, planning for a severe flood that is not likely to occur may have an economic impact that is unacceptable as well. This is especially the case when major facilities already exist in the flood prone area.

A knowledge of expected flooding allows the design and location of facilities and functional activities to ensure maximum protection of materiel and personnel during a flood crisis. The knowledge enables agencies to evaluate the adequacy of existing measures--regulations, policies, operations plans--and the location of operations in existing facilities also for reasons of economy, safety, and continuance of operations.

The degree to which land use plans and existing measures may be altered and the additional costs that may be incurred through compliance with EO 11988 depend on the determination of what constitutes the flood plain.

EO 11988 defines the "base flood" as "that flood which has a one percent or greater chance of occurrence in any given year [30:5]." The provisions of EO 11988 apply to all federal activities within areas affected by that flood (the so called 100-year flood) (25:1). For critical facilities such as hazardous chemical or fuel storage or hospitals where evacuation of patients would be difficult, Department of Defense (DOD) instructions set the flood plain at that area subject to a 0.2 percent or greater chance of flooding in any given year (the so called 500-year flood) (25:2).

Through the years, several elevations have been used as a basis for decisions affecting the Huffman Basin. The designed spillway elevation of Huffman Dam and the deed restrictions of Huffman Basin are based upon the "official planned flood"[3] estimated by the MCD prior to 1920 (19).

The Corps of Engineers (COE), U.S. Army, Cincinnati District estimated the 100-year flood at 815 feet MSL in 1941. The COE, Louisville District updated that estimate in 1953 recognizing the 100-year flood at 810 feet MSL. The conflicting figures were addressed in a letter from the Louisville District dated, 28 July 1953, but the reasoning behind the determination of these figures was

---

[3]Official planned flood: the projected flood level which Huffman Dam was designed to protect against.

not provided making it impossible to rationally select which criteria to use (3).

The Environmental Planning Section of the Engineering Branch of Base Civil Engineering, WPAFB bases its actions on an assumed base flood elevation of 825 feet MSL (9). The policy ensures that the base evaluates the possibility of flooding for facilities controlled by deed restrictions.

An analysis of flood elevation observations recorded between 1922 and 1977 provides a basis for evaluation of flood probabilities. This information is necessary for the base to effectively comply with EO 11988 and DOD criteria on construction activities (25).

DOD instructions state that each project:

> . . . must be in accordance with the standards and criteria and consistent with the intent of the National Flood Insurance Program, . . . and may deviate from this only to the extent that the standards . . . are demonstrably inappropriate for the project [25:3].

The instruction goes on to state:

> Individual projects must be separately assessed but examples of a situation where the "demonstrably inappropriate" criteria might apply could be an aircraft hangar (which cannot be raised above the aircraft apron elevation) at an existing installation in a flood plain. . . . However, even in such cases, all reasonable actions must be taken to "flood proof" the project and to design or modify the project to minimize potential harm to or within the flood plain [25:3].

Even if flood elevation probabilities are known, there must be a way of associating those probabilities with

expected costs in order for base planners to determine what actions are reasonable to "flood proof" or minimize potential harm to base facilities. There is no method of construction estimating specifically designed to predict flood damage to facilities before a flood occurs. A preliminary analysis of the flood risk and a description of the process of evaluating that risk is necessary to determine whether a detailed damage estimate of a number of facilities is justified and to guide that estimating process if it is undertaken.

Objectives

The purpose of this research was threefold:

1. To examine the basis of flood predictions for the Huffman Dam flood plain and establish flood elevation probabilities.

2. To explore methods for predicting the degree of damage to structures, real property installed equipment, building contents, and other real property as a function of flood elevation.

3. To develop a measurement tool to quantify the monetary loss expected for flooding at various elevations, which can then be used to evaluate alternatives to reduce potential flood damage.

Scope

A key consideration in defining the scope of the research and stating the research questions to be answered is the purpose that the report is intended to serve. A common "engineering economics" approach to economic analysis is to base a decision to take action on an evaluation of the cost of each proposed alternative and on a calculation of the benefits to be gained (11:135). This cost-benefit analysis weighs the cost of flood protection measures against the expected benefits to be gained from flood protection. The benefits to be gained by flood protection are taken as the amount of damage that would have occurred if protection was not provided (8:287).

Flood protection can be provided in many ways. Specific methods are not described here, but the wide variety of methods, or combinations of methods, that may be considered are illustrated in Figure 5 (13:13).

A clarification of purpose is necessary to ensure that the scope of the research is consistent with stated objectives of this report. The approach taken by the authors differed somewhat from the "engineering economics" approach described above, because the purpose of the study was not to propose or evaluate specific engineering proposals. The authors believe that flood protection is just one consideration that should be examined in the context of other mission requirements, and the evaluation of

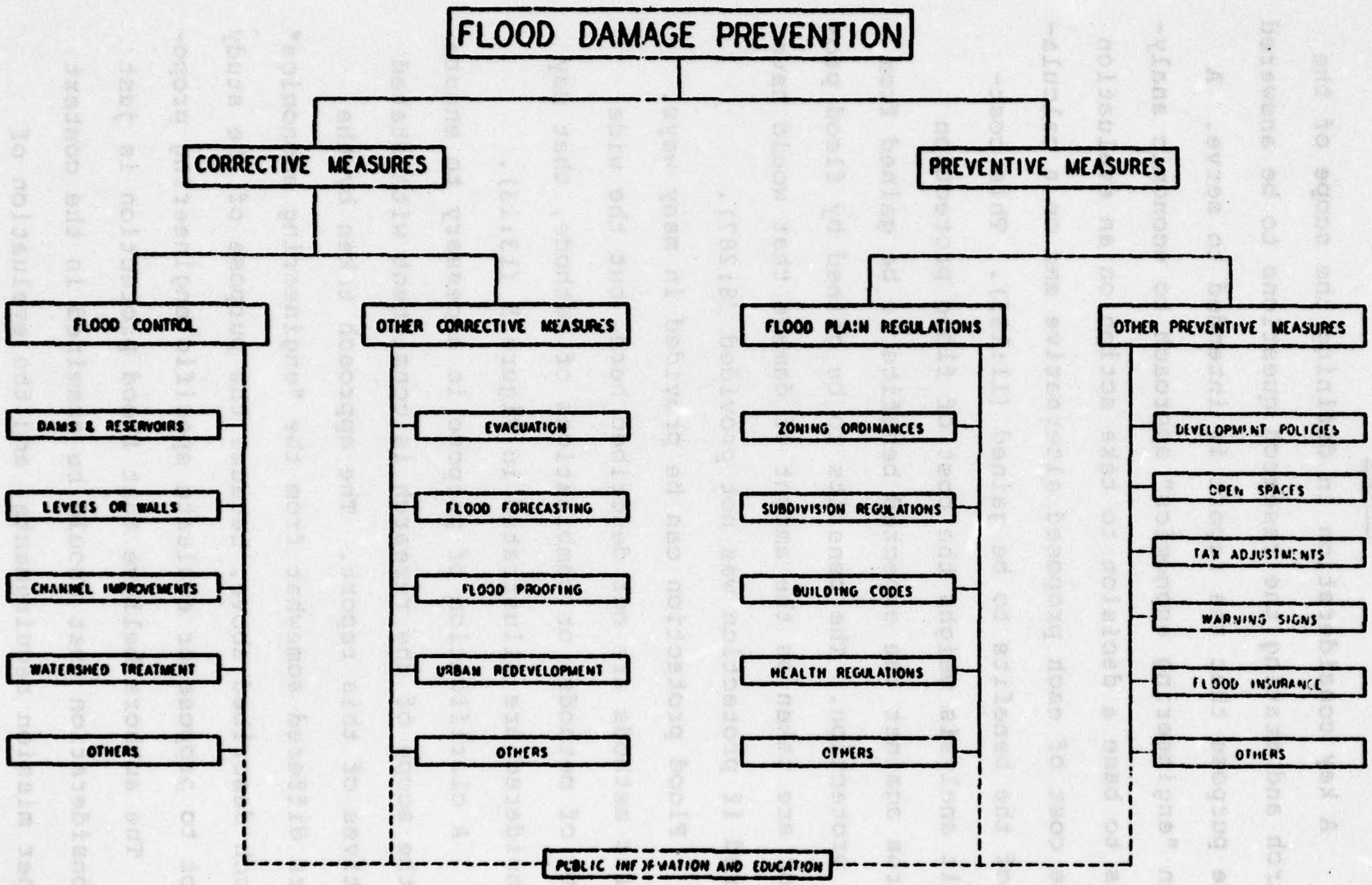


Fig. 5. Flood Damage Prevention Measures (13:13)

specific alternatives is a continuing function performed by appropriate staff agencies as part of the validation of every project. The purpose of this study was to explore quantitative techniques to estimate expected damages of flooding.

The discussion was intended to provide direction to the evaluation of the potential flood hazard and to the selection of possible alternatives to provide adequate flood protection. The damage estimates obtained as a result of using these techniques can then be considered as measures of expected benefits in future economic analyses of engineered proposals.

Benefits are generally measured as the amount of reduction in flood damage to property and in interruption of operations. Direct flood damages are defined as physical damages to property caused by flood waters (22:p.II-4). Indirect flood losses include the net economic losses of goods and services due to interruption of activities both inside and outside of the flooded area, and the cost of emergency actions made necessary by the flood (22:p.II-5).

This research addressed only direct flood damages. In the process of the study, facilities affected at each flood elevation and expected damages sustained by those facilities were identified. The relative importance of continuous operation of those facilities affecting the

base mission must be considered by base authorities, in conjunction with the economic impacts described in this study, before flood plain management plans are implemented.

The natural processes which affect flooding in the Huffman Basin occur within the 671 square mile Mad River watershed shown in Figure 6. The limits of the actual retarding basin have been designated by the MCD as the area within the 835 MSL contour, and corresponds to the spillway height of Huffman Dam. An analysis of the area within the boundaries of WPAFB and lying in the retarding basin was made to determine the probabilities of flooding and the extent of damage to facilities.

Specific facilities were selected for investigation as they were determined to be affected by flooding at the 500-year flood elevation. The COE limits its studies to areas affected by a maximum of the 500-year flood or the Standard Project Flood. The Standard Project Flood is the flood that may be expected from the most severe combination of weather, climatic, and hydrologic conditions that are considered reasonably characteristic of the watershed (2:6). The 500-year flood is the maximium consideration for critical facilities required by DOD instructions (25:2).

The subject areas investigated in the research effort are presented in the following plan of the report.

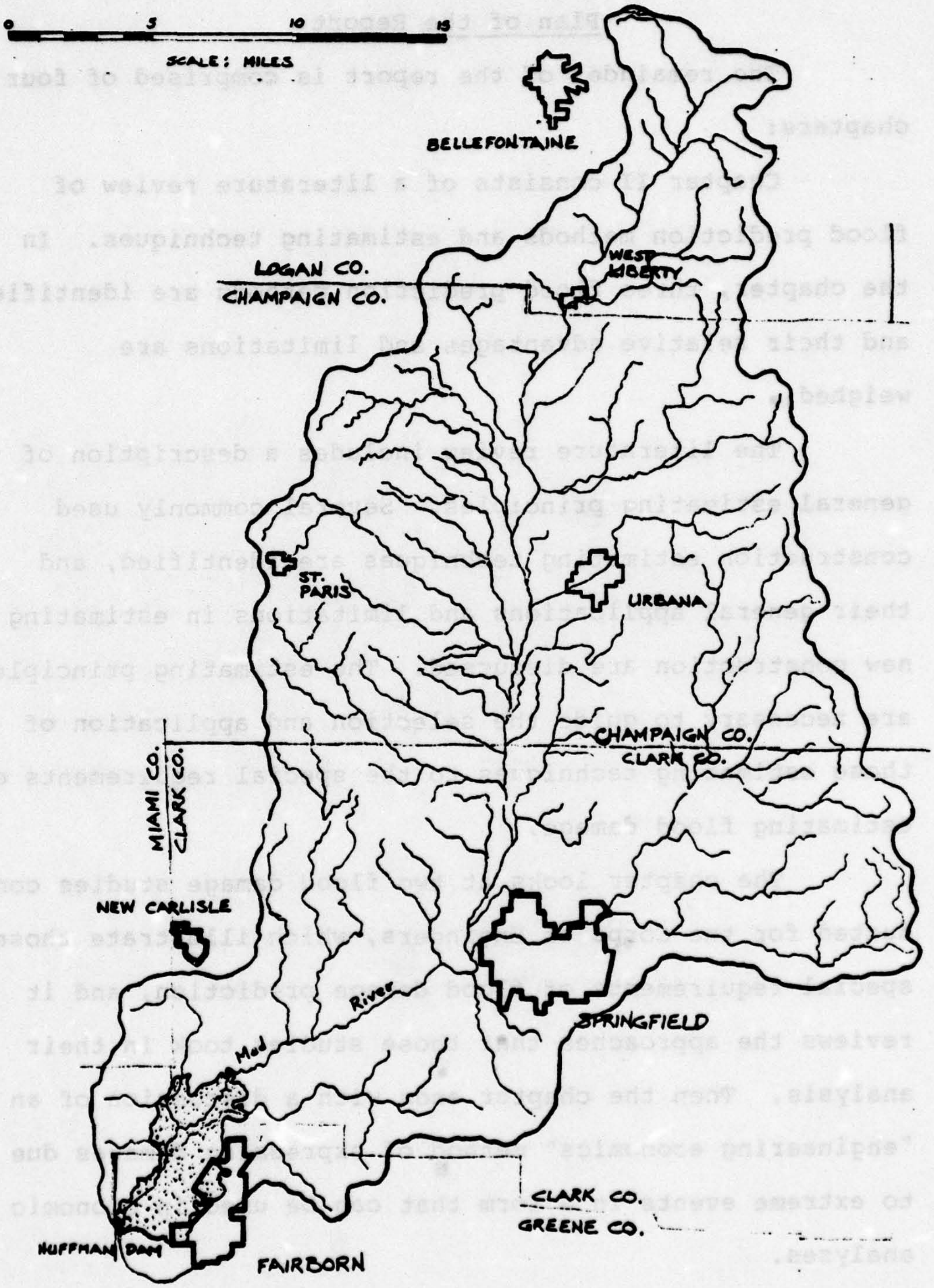


Fig. 6. Huffman Dam Watershed (Mad River System) (33:328)

Plan of the Report

The remainder of the report is comprised of four chapters:

Chapter II consists of a literature review of flood prediction methods and estimating techniques. In the chapter, three flood prediction methods are identified and their relative advantages and limitations are weighed.

The literature review includes a description of general estimating principles. Several commonly used construction estimating techniques are identified, and their general applications and limitations in estimating new construction are discussed. The estimating principles are necessary to guide the selection and application of those estimating techniques to the special requirements of estimating flood damage.

The chapter looks at two flood damage studies conducted for the Corps of Engineers, which illustrate those special requirements of flood damage prediction, and it reviews the approaches that those studies took in their analysis. Then the chapter ends with a discussion of an "engineering economics" method of expressing damages due to extreme events in a form that can be used in economic analyses.

Chapter III explains the selection of a flood prediction method and develops the methodology to apply that

analysis to obtain flood elevation probabilities for the Huffman Basin. The chapter describes the procedure used to identify buildings subject to flooding at the 100 and 500 year frequency elevation. The steps taken to explore the use of alternative estimating techniques are described, and computer programs to assist in the assessment of the impact of flooding on the facilities at WAPFB are developed.

Chapter IV consists of the findings of the research. The chapter states the probability of flooding at selected levels and the computed elevations of given N-year recurrence intervals, then buildings within the flood plain are identified. The findings of the analysis of COE flood damage studies and flood damage surveys are presented, and their implications to the study of potential flooding at WPAFB are discussed. Finally in Chapter IV, the use of the programs developed in Chapter III to assess the impact of flooding at WPAFB is demonstrated, and observations obtained from the building classification process are presented.

Chapter V concludes the report. The chapter contains a summary of the research objectives and of the results that were obtained. The chapter recommends steps to obtain the expected value of flood damage, and offers an interpretation of the expected values as they may be used in economic analyses.

CHAPTER II

LITERATURE REVIEW

The first part of the research process was a literature review. The purpose of the review was to survey what is currently known about flood prediction and damage estimation, and to set a foundation from which the research could proceed.

This chapter is divided into four sections. The first section identifies and analyzes three methods commonly used in the field of hydrological[4] engineering to predict the expected frequency of floods. The second section, presents basic estimating principles that apply to the generalized estimating process described in Air Force Systems Command Manual 173-1, Cost Estimating Procedures (6). The third section identifies commonly used construction estimating techniques and describes their usual application by construction estimators. The fourth section reviews two COE flood damage studies and some of the methods they used to obtain and analyze data. The section also analyzes a method of weighing the

[4]Hydrological: Pertaining to hydrology, which is: "the science that treats of the waters of the Earth, their occurrence, circulation, and distribution, their chemical and physical properties, and their reaction with their environment . . . [14:8]."

probability of an extreme event and the damages caused by that event in order to assign an expected value of damages to be considered in an economic analysis.

Flood Prediction

The probability of waters reaching a defined flood elevation is a basic parameter in the design efforts of the hydrological engineer. Basic texts in water resources engineering provide a rich source of methods which have been and are used in determining flood stage probabilities.

Linsley and Franzini's Water Resources Engineering (14) provides chapters in (1) "Descriptive Hydrology," (2) "Quantitative Hydrology," and (3) "Probability Concepts in Design." Descriptive hydrology provides a description of the parameters defining the processes of the Earth's waters including their occurrence, circulation, and distribution. Some of those parameters are precipitation, vegetation, slope, and soil type (14:8-37). Quantitative hydrology adds quantitative analysis to these processes, and describes the basic methods engineers use to predict runoff and streamflow quantities, including temporary storage in basins (14:38-71). Probability concepts address the uncertainties of flows and the use of descriptive statistics of past events to predict future runoff and flows (14:110-134).

Pickel's Drainage and Flood Control Engineering (24) addresses similar methods and techniques as Linsley and Franzini, but also integrates these techniques into the hydrology of the Miami Valley of which the Huffman Basin is a component.

Another source of information on hydrological methods, and one which bears directly on the Huffman Basin is the Report of the Chief Engineer of the Miami Conservancy District published in 1916 (18). The report details the actual flood protection plan for the Miami Valley. That flood protection plan was the result of months of study by Arthur E. Morgan. It has been acclaimed as a landmark in the field of hydrological engineering which is said to have developed with Morgan and the Miami Conservancy District (5:115).

The original determination in 1913 by Morgan Engineering Company of the amount of flow that the design of Huffman Dam was to control was based on the maximum rate of flow during the flood of March 22-27, 1913 (18:63). The rate of flow was determined by surveys of highwater lines along the edges of valleys and along the banks of the rivers and streams. Combining these high water marks and a cross section survey of the valley or stream bed, the cross sectional area of the flow was determined. This then could be applied to Kutter's formula, which at that time was the best-known and most

widely used formula for computing the flow of water in open channels (24:129).

The formula expressed in English units is as follows (24:129):

$$V = \frac{41.6 + 1.811/n + 0.00281/s}{1 + (41.6 + .00281/s)\ (n/\sqrt{r})}\ (\sqrt{rs})$$

in which,

V = mean velocity in feet per second

s = slope or fall per foot

r = hydraulic radius or cross sectional area divided by the wetted perimeter

n = a coefficient dependent upon the channel characteristics which cause retardation of flow, such as surface roughness, vegetation, obstructions or irregular cross section.

Using Kutter's formula produces a result only as accurate as the determination of the empirical "n," the retardation coefficient. As may be seen in Table 1, the range of values for "n" in a natural stream is from .025 to .150 with incremental differences within stream classifications varying as much as from .0025 to .025 or 10 to 17 percent of the overall "n" value. The incremental differences are based on an engineer's judgment of whether the stream's surface is perfect, good, fair, or bad, which are undefined characteristics.

TABLE 1

COEFFICIENTS OF RETARDATION

Surface	Perfect	Good	Fair	Bad
Natural Stream Channels				
1. Clean, straight bank, full stage, no rifts or deep pools	0.025	0.0275	0.030	0.033
2. Same as (1), but some weeds and stones	0.030	0.033	0.035	0.040
3. Winding, some pools and shoals, clean	0.033	0.035	0.040	0.045
4. Same as (3), lower stages, more ineffective slopes and sections	0.040	0.045	0.050	0.055
5. Same as (3), some weeds and stones	0.035	0.040	0.045	0.050
6. Same as (4), stony sections	0.045	0.050	0.055	0.060
7. Sluggish river reaches, rather weedy or with very deep pools	0.050	0.060	0.070	0.080
8. Very weedy reaches	0.075	0.100	0.125	0.150

SOURCE: (18:133).

In computing flows for an entire watershed using the above method the value of "n" must be judged for composite areas of varying channel characteristics, making possible even greater errors than the 10 to 17 percent in judgment of surface type. Although the method used by the Morgan Engineering Company was the best available given that the detention basin (Huffman Dam) was not constructed yet, it was apparently subject to 10 to 17 percent or greater variation dependent upon subjective judgment.

Other methods used by hydrological engineers are presented in handbooks such as the Standard Handbook for Civil Engineers edited by Frederick S. Merrit (15). The book is an anthology of many of the empirical formulas presently used in hydrological engineering.

The U.S. Army Corps of Engineers, in its discharge of public works responsibilities, relies largely on the Deliberate Method of Runoff Estimation developed by Hathaway and Horton and explained in detail in Part XIII of the U.S. Army Engineering Manual for Military Construction, Damage and Erosion Control (29).

The COE uses the "Deliberate Method" for its more precise calculation of surface runoff. This estimation converts rainfall rates into runoff at a point in a stream. The rainfall rates used are usually the probable maximum storm to be expected within an interval, as

represented in isohyetal maps such as is shown for the twenty-five year rainfall in Figure 7. The method uses Horton's equation [29:p.2-7].

$$q = \tanh^2 \sigma[0.922t(\sigma/nL)^{0.50}S^{0.25}]$$

where:

q = rate of flow, in cubic feet per second per acre of drainage area

σ = rate of rainfall in excess of the rate of soil infiltration in inches per hour

t = time or duration in minutes

n = coefficent of retardation (see Table 1)

$\tanh^2$ = hyperbolic tangent squared

L = length of flow in feet

S = slope of surface

The storm runoff supply curve shown in Figure 8 corresponds to a maximum rainfall rate, which would be determined from an isohyetal map. The cumulative supply at a point can be determined using these two figures (isohyetal map and rate of runoff curve). The isohyetal map determines which set of runoff curves are used. The curve shown represents that selected for a region on the isohyetal map corresponding to a rainfall of 2.8 inches per hour. Each separate curve represents a different length of stream from L=20 feet to L=1200 feet, which is the

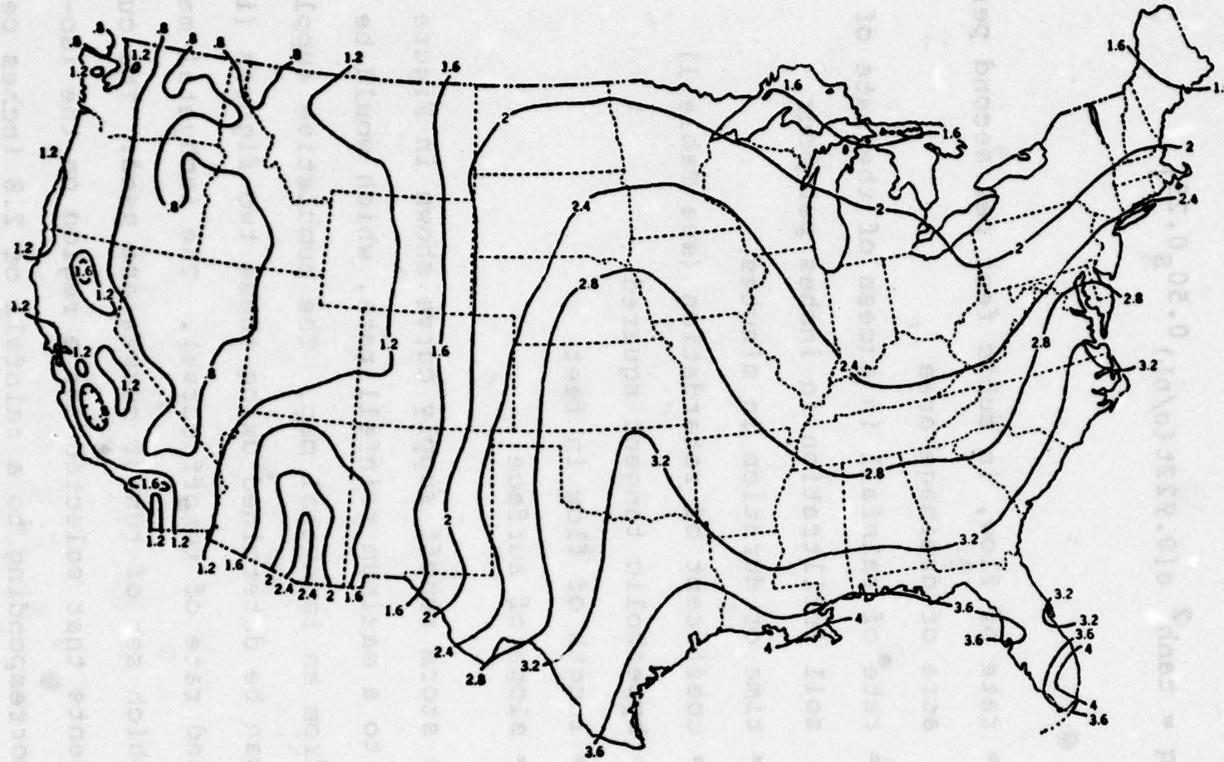


Fig. 7. One-Hour Rainfall to be Expected Once on the Average in Twenty-Five Years (U.S. Weather Bureau)

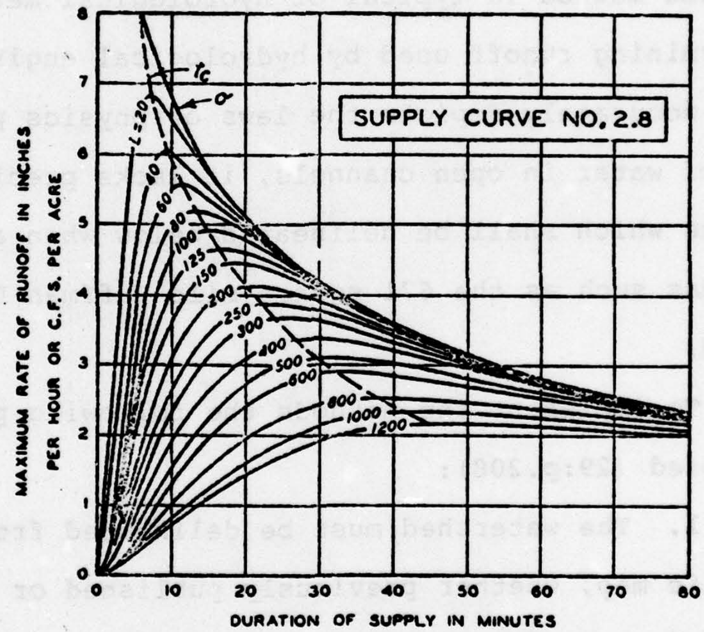


Fig. 8. Rate of Runoff Curves for a 2.8 Inch per Hour Rainfall (29:p.2-10)

distance from the farthest reach of the watershed to the point for which flow data is to be determined. The value "T_c" on this curve represents the "time of concentration" or peak flow which corresponds to an instantaneous value of "σ" and "t" on the axes of the graph. The values are substituted into Horton's equation to determine the flow rate.

The method is typical of hydrological methods for determining runoff used by hydrological engineers. While it accurately depicts the laws of physics pertaining to flow of water in open channels, it lacks precision due to factors which shall be delineated below when applied to large areas such as the 671 square mile Huffman Dam watershed.

To implement the methods the following procedures must be used (29:p.208):

1. The watershed must be delineated from a topographic map, whether previously published or prepared from ground or aerial surveys especially for this project. The available maps of the U.S. Geological Survey, 7.5 minute series, are scaled to approximatley one inch equal 2,000 feet. Subareas must then be delineated into small areas of overland flow.

2. The vegetation, soil, and pavements of the small areas must be determined to select the retardation coefficient "n" of each area.

3. The path of flow must be selected from the maps or observations of rainstorms and the length and slope of each path measured.

4. For successive areas, as flows combine, a weighted equivalent length must be computed,

$$L_E = \frac{A_1 L_{E_1} + A_2 L_{E_2} + \ldots}{A^1 + A_2 + \ldots}$$

where

L_E = equivalent length

A = area

5. The design storm rainfall is selected from the isohyetal map, and the corresponding supply curve, such as in Figure 8, is selected.

6. A rate of infiltration is selected from a study of the soil and the surfaces of small areas. Using his judgment, the engineer assigns infiltration rates in accordance with Table 2. The supply σ in Horton's formula is equal to the rainfall rate minus the infiltration rate.

For the weighted supply rate of the many areas,

$$\text{Weighted } \sigma = \frac{A_1\sigma_1 + A_2\sigma_2 + \ldots}{A_1 + A_2 + \ldots}$$

where

A = area

σ = area supply rate - area infiltration rate.

TABLE 2

INFILTRATION RATES (FOR 1 HOUR) IN INCHES PER HOUR

Major Divisions		Letter		Dense Cover	Average Cover	Sparse (Bare) Cover
Coarse Grained	Gravel and Gravelly Soils	GW		1.0 - 1.5	0.8 - 1.2	0.6 - 1.0
		GP		1.0 - 1.5	0.8 - 1.2	0.6 - 1.0
		GM	d	0.6 - 0.8	0.4 - 0.6	0.2 - 0.4
			u	0.4 - 0.5	0.3 - 0.4	0.2 - 0.3
		GC		0.3 - 0.4	0.2 - 0.3	0.1 - 0.2
	Sand and Sandy Soils	SW		1.0 - 1.5	0.8 - 1.2	0.6 - 1.0
		SP		1.0 - 1.5	0.8 - 1.2	0.6 - 1.0
			d	0.6 - 0.8	0.4 - 0.6	0.2 - 0.4
			u	0.4 - 0.5	0.3 - 0.4	0.2 - 0.3
		SC		0.3 - 0.4	0.2 - 0.3	0.1 - 0.2

TABLE 2--Continued

Major Divisions		Letter	Dense Cover	Average Cover	Sparse (Bare) Cover
FINE GRAINED	SILTS & CLAYS WL 50	CL	0.1 - 0.2	0.1 - 0.2	0.02 - 0.1
		ML	0.6 - 0.8	0.4 - 0.6	0.2 - 0.4
		OL	0.6 - 0.8	0.4 - 0.6	0.2 - 0.4
	SILTS & CLAYS WL 50	CH	0.1 - 0.2	0.1 - 0.2	0.02 - 0.1
		MH	0.6 - 0.8	0.4 - 0.6	0.2 - 0.4
		OH	0.1 - 0.2	0.1 - 0.2	0.02 - 0.1
HIGHLY ORGANIC	SOILS	PT	0.6 - 0.8	0.4 - 0.6	0.2 - 0.4

SOURCE: (29:p.2-15).

7. The rate of runoff at the dam would equal the "q" of Horton's formula multiplied by area. Subtracting the outflow of Huffman Dam would yield the amount of water stored.

Because of its complexity, direct application of the "Deliberate Method" is generally confined to small areas.

More recent publications appear to make use of computers to provide more detail in the analysis methods described in the previously referenced sources (1). The COE has been especially active in commissioning studies in this area. The Preliminary Review and Analysis of Flood Control Project Evaluation Procedures (12) and Proceedings of a Seminar on Computer Applications in Hydrology (27) are examples of this type of study.

All of these methods are based upon empirical formulas using as input variables, rainfall, infiltration, evaporation, vegetation, soils types, and topography. Since all of these parameters vary considerably in even a small area under study, the most detailed studies are still aggregates of many small area approximations.

The computer methods are frequently used to enable the flow from many areas to be aggregated into a flow value at a single point downstream.

In contrast to the previously defined methods of determining runoff, statistical methods based on actual

observations appear to provide the most accurate determination of flood probabilities. Annual flooding in many watersheds appears to occur as a recognizable distribution of events when peak flood flows are plotted against numbers of occurrences (19:110).

The recurrence interval is defined as the average interval in years between the occurrence of a flood of a specified magnitude and the occurrence of an equal or larger flood. The "m"th largest flood in a data series has been equalled or exceeded "m" times in a period of record, "N" years, and the best estimate of its recurrence interval "t_p" is:

$$t_p = \frac{N+1}{m} \qquad [19:114]$$

A SIMFIT[5] analysis of recorded flood events in the Record of the Huffman Retarding Basin operations (16) indicates a negative exponential distribution of maximum flood elevations when grouped by number of occurrences, which is similar to the results Linsley and Franzini show in a study of flood peaks on the Susquehanna River at Harrisburg, Pennsylvania (14:111).

---

[5] SIMFIT: A computer program which determines he fit of a group of data elements to each of a set of standard distributions using Chi-Square analysis techniques (32:501).

In a series of conversations with Mr. Rozelle, Assistant Chief Engineer for Flood Control of the Miami Conservancy District, he stated that MCD's analysis of flood probabilities included calculated values of floods which would have occurred if the dam had been constructed in the nineteenth century and had retained the great floods which occurred as far back as 1804. Linsley and Franzini (14:112) caution against combining data collected under dissimilar conditions.

It is possible to include calculated flood peaks of events which occurred prior to the construction of Huffman Dam in the analysis, but the accuracy of these estimates may not be comparable with the actual observed data of the operating record of the basin, since they are based on observed high water marks to which Kutter's formula has been applied.

Sources of data which may be applied to the Miami Valley, particularly the Huffman Dam watershed are mainly found in the records maintained by the Miami Conservancy District since its inception in 1915. The records of principle interest to this study were:

1. Record of Huffman Retarding Basin Operations (16). These records are included as "Appendix A" of this study.

2. Precipitation records gathered by agents of the MCD at various points within the Mad River watershed

on a daily basis--these are unpublished records on file in the MCD, Dayton, Ohio, office.

3. The Technical Reports of the Miami Conservancy District (33).

Estimating Principles

With a flood prediction method selected and data available with which to apply that method, an investigation was begun to find estimating techniques that could predict the extent of damages that may occur to facilities subject to flooding.

Construction estimating techniques are normally thought of as being directed toward determining the contract cost of proposed new construction, but they may be applied, also to determine costs to repair or restore a damaged facility. Usually, damage estimation is accomplished after damage has occurred or is beginning to occur, and involves totaling the costs to repair or replace specifically identified, damaged items. In a situation where the estimate is accomplished before damage has occurred it, may be difficult to apply any single technique as a predictor of damage rather than as a summary of damage. The estimating relationships used by these techniques are developed through basic estimating principles. These estimating principles must be used to

guide the selection and application of estimating techniques to achieve the estimator's objectives.

There are two objectives in estimating which often create conflicting interests. The estimator is expected to render a reasonably accurate appraisal of cost. He is also asked to execute this task within time constraints that generally are too short to permit an extensive analysis of every construction detail (10:42). Therefore, it is necessary for the estimator to develop estimating techniques that allow him to find and use existing data in a quick analysis to effectively predict costs. The ability to recognize the depths and degree of accuracy required for a specific estimate is equally important, since the time and costs involved are directly related to the degree of accuracy required (17:40). In order for the estimator to accomplish these objectives he must be able to visualize specific types of construction and reduce his observation to a quantification of cost. And finally, he must be able to apply an analytical approach that leads to a solution (10:42).

Air Force Systems Command Manual 173-1, Cost Estimating Procedures (AFSCM 173-1) defines estimating as the "process of projecting financial requirements to accomplish a specified task [6:p.1-1]." The primary estimating tasks are (6:p.1-1):

1. Defining and planning the estimating task.

2. Selecting the estimating structure for preparing cost data.

3. Collecting, evaluating, and applying the necessary cost and cost-related data.

4. Applying the proper estimating methods.

5. Documenting the estimate so that it can be used in the decision-making process.

<u>Defining and Planning the Estimating Task</u>

The estimate's validity, completeness, and credibility depend in large measure upon the clear and early definition of the estimate's purpose and type, and a complete description of what is to be costed (6:p.1-3).

The use to be made of the estimate determines the scope of costs covered, the level of detail required, and the data and estimating methods to be used. One such use of the completed cost estimate is for budgetary planning and control (6:pp.2-1,2-2).

An adequate system description is required to develop an appreciation of the considerations that have important impacts on cost (6:p.2-2). Some of the facets on which data may be collected and analyzed are mission or output of the system, physical and performance characteristics, and operational concepts or allowable inputs to the system. The estimator must investigate all facets to identify estimating relationships and other cost-related

information, he must look for information on past estimates for the system and estimates for analogous systems, and he must identify the ground rules or constraints that he will be working with. Some examples of constraints are the following (6:p.2-3).

1. When must the estimate be completed?

2. Will components or functional-type cost items be estimated, and at what level of the work breakdown structure will costs be estimated?

3. Are price levels to be held constant or inflated?

4. Will costs be calculated at a single output level or at several levels, for example, for a 10-year, 50-year, or 100-year flood?

Selecting the Estimating Structure for Preparing Cost Data

The work breakdown structure (WBS)[6] constitutes the framework for the estimate and for data collection. In defining the estimating task, the estimator should determine which items apply to the estimating job and the level of aggregation[7] to be used for each item selected.

---

[6]Work breakdown structure: Groups of similar cost elements classified at varying levels of information each of which is a more detailed breakdown of the preceding level (6:p.2-5).

[7]Aggregation: The grouping of individual components into larger components or subsystems to be studied as a whole.

The depth to which the estimate can be prepared is based on availability of data, methodology to be employed, and information necessary to support the estimate's purpose (6:p.2-5).

Collecting, Evaluating, and Applying the Necessary Cost and Cost-Related Data

In collecting data the estimator must consider quantity, comparability, quality, and relevancy. To satisfy all of these conditions, the estimator must first have knowledge of the data sources at his disposal, and second, apply his experience, judgment, and ingenuity to relate these data sources and considerations to a particular estimating problem (6:p.3-1).

The quantity of relevant supporting data is important to obtaining a degree of confidence in an estimate based on statistical techniques. But caution must be observed in increasing the total quantity of data to ensure that the comparability, quality, and relevance of the data are not degraded (6:p.3-1).

Comparability must be considered when historical data is taken from an analogous system to ensure that the cost data is uniformly defined for both systems (6:p.3-1).

The quality of historical data must be considered to ensure that a bias is not inadvertently incorporated in the analysis. The estimator must pay attention to the

purpose for which the data was originally compiled and the procedures that were used in its development (6:p.3-2).

The relevancy must be considered to ensure that the data can contribute to the development of a meaningful cost relationship for the facet of the system being described (6:p.3-2).

There are two basic data source categories. The first provides a record of costs for a particular system, and includes actual records, reports, and study proposals. The second provides standard cost or cost-related data that apply across-the-board to many systems. These general experience sources can be further classified into statistical summaries, catalog compendiums, and estimating relationship studies (6:p.3-2). More than one data source may be required when no single, generally accepted estimating relationship is available (6:p.3-3).

Applying the Proper Estimating Methods

There are several ways of projecting cost associated with a system (6:p.4-1).

1. Estimating relationships (ERs).
2. Specific analogies.
3. Specialist estimates.
4. Rates, factors, and catalog prices.
5. Cost model applications.

The selection of a particular estimating method is guided by several considerations which were discussed under the first three estimating tasks, including the type of estimate required, the level of detail, and the availability of data (6:p.4-1).

1. The costs associated with a system may vary with system characteristics. The estimator must select the appropriate estimating relationships and consider the availability of statistical information (6:p.4-1). "Cost to noncost" ERs are frequently used to estimate costs, for example, building replacement cost estimated as a function of type of exterior wall construction (6:p.4-1) (examples mine). Or "cost to cost" ERs may be used, for example, to estimate building replacement cost as a function of original construction cost. The procedure for developing estimating relationships is to: (a) designate and define a dependent variable, (b) select the parameters to be tested as potential independent variables, (c) collect data on the independent and dependent variables to be correlated, (d) use statistical analysis to explore relationships, and (e) determine the relationships that best describe the data (6:pp.A3-1 to A3-3).

2. Specific analogies depend upon the known cost of an item in another system as the basis for the cost of a similar item in the focal system. Adjustments are made to known costs to account for differences in the systems.

The specific analogy method requires that the estimator examine both the known and the similar item to determine the major cost-related characteristics, examine the technical aspects of the cost-related elements to verify their similarity and assess the design, material, and operations implications to the cost estimate (6:p.4-2).

3. Special estimates may be obtained from an organization or person having specialized knowledge. In addition, specialists can often assist the estimator in applying or developing specific analogies (6:p.4-2).

4. Costs may also be projected through the application of rates, factors, and catalog prices. Rates are set prices usually based on historical experience plus judgment relative to future price level trends. Factors represent average costs or ratios of costs for designated types of products or services. Catalog prices represent published prices for standard off-the-shelf products or services (6:p.4-2). In construction, this type of information is usually found in construction estimating guides. Two such estimators are <u>Building Construction Cost Data</u> (4) published by the Robert S. Means Company and the <u>National Repair and Remodeling Estimator</u> by Albert S. Paxton (23).

5. A cost model consists of the cost estimating logic used to derive a cost estimate. The unique

contribution offered by a model exists within the logic framework which structures the application of the cost estimating techniques. The simplest form of a model might be a checklist of program elements, used to avoid omitting relevant elements from an estimate. The most complex form might be a computerized life-cycle estimating program complete with ERs, factors, analogies, and catalog prices. The model concept is applicable to all levels of estimating (6:p.4-3). But the estimating logic developed in the model must be documented so the results can be evaluated and used in the decision-making process.

Documenting the Estimate so that it can be used in the Decision-Making Process

Documentation should identify the purpose of the estimate, describe the system factors considered to influence cost, describe the data and methods used in developing the estimate, and discuss areas of uncertainty that are likely to have significant impact on costs (6:pp.6-1,6-2).

Uncertainties in estimating concern data and their treatment in preparing the estimate. The major causes of estimate uncertainty are inability to measure cost precisely, inadequacy of usable data, statistical uncertainty, errors in the treatment of these data, and errors of judgment. The cost estimator has four objectives in treating cost estimating uncertainties (6:p.4-6):

1. Reduce the uncertainties surrounding the estimate.

2. Assess both the reasons for and the dollar impact of the remaining uncertainty.

3. Convey the degree of uncertainty to the estimate's user.

4. Guide the user in interpreting the estimator's conclusions.

The confidence analysis reflects the estimator's judgment of the degree of uncertainty involved. The statement of confidence may take several forms (6:pp.6-3,6-4).

1. Ranging the total system cost.

2. Providing alternative costs for various possible resulting states of the system.

3. Cost sensitivity analysis pointing out the cost impacts of varying assumptions made in the estimate.

4. Statistical error, upper and lower bound of the cost, and quantitative judgment statements.

When an estimated figure has been established and the uncertainty associated with that figure has been explained so that the user can determine the meaning of the figure to the decision being made, the documentation step has been accomplished.

The five estimating tasks applied to construction activities have developed into several common construction

estimating techniques that may be used directly or modified for use in the estimation of flood damages.

Construction Estimating

Construction estimating techniques are often described by their level of estimating accuracy[8] as determined by the purpose of the estimate.

> "Ball park" estimates pertain to large quantities or blocks of the entire project and are used mostly to determine the preliminary feasibility of the project. . . .
>
> The "Unit-Cost" estimate bases the cost on various units of the project. The degree of accuracy is directly related to the . . . [ability to accurately count] the number of units involved in the project. Also, the greater number of units the project can be subdivided into, the more accurate the cost estimate becomes. This is best accomplished after . . . [an appropriate analysis] has been completed showing the different essential aspects of the project . . .
>
> "Take-off" estimates provide the most accurate form of estimating because they require a complete material take-off from complete architectural and engineering drawings [17:40].

In his article "Cost Estimating Techniques," John Molnar, president of Molnar Engineering, Inc., recommends that facilities managers use primarily the "unit-cost" estimating methods because they frequently find themselves having to perform in an engineering area foreign to them (17:41).

There are several generally recognized types of construction estimating techniques. Most of them involve

---

[8]Estimating accuracy: in construction estimating this is usually measured in terms of how well the estimate predicts the amount eventually paid a contractor for a project.

varying combinations of "unit-cost" or "take-off" methods to achieve a desired level of accuracy. Ten such techniques were identified in a survey of some of the largest Architect-Engineering firms in the nation conducted by the Office of Contruction of the Veterans Administration (10:44).

The first three methods used quantity "take-off" techniques. The "take-off" technique is a quantitative analysis of all labor, supplies, and material costs. The "modular quantity take-off" is an analysis of a representative module of the building extrapolated to the entire building, plus the estimator's assessment of common central systems. The "partial quantity take-off" is a thorough analysis of known requirements with a percentage or a rough estimate added for details that have not been worked out. It often is the best obtainable estimate when a complete take-off cannot be made (10:44). The "take-off" approach breaks the construction process down to its most basic components for precise analysis, but it's precision is limited for flood damage estimating due to judgments that must be made concerning the extent of damage that might occur. The limited precision obtainable may not justify the increased complexity of the estimating task.

The next four techniques are based on historical unit costs. The "square-foot" and "cubic-foot" estimates

are based on historical data related to each square foot of gross area or each cubic foot of the building's total volume. The "unit of enclosure" estimate relates all costs to a square foot of enclosure. The total surface of the enclosure is defined as the sum of the area for all floors, perimeter and partition walls, and roof. The "unit of use" estimate relates all costs to a functional unit, e.g., patient, student, car space, etc. (10:44). The "unit-cost" approach is based on developing cost to non-cost estimating relationships tying costs to a measurable characteristics that varies among otherwise similar buildings.

The eighth and ninth techniques narrow the analysis to unit costs of smaller building subsystems but maintain the level of aggregation above that of a take-off method. The "systems unit" cost estimate uses historical data for identifiable parameters of a building--site work, foundation, floor, roof, exterior walls, doors, interior walls, equipment, electrical, plumbing, and HVAC.[9] Units of measure reflect those normally used in estimating--square foot, lump sum, plumbing fixture unit, air conditioning ton, equipment item, etc. The "finish unit" cost estimate may be called a combination of historical

---

[9]HVAC: Heating ventilating and air conditioning system.

unit cost and systems unit cost techniques. It employs historical data to establish a common unit-cost per square foot of common building elements--site, foundations, structure, roof, perimeter wall and such central systems a HVAC and electrical equipment, and adds discrete departmental unit costs, which include partitions, finishes and local equipment (10:44).

The final estimating technique indentified by the survey was regression and correlation analysis. The technique predicts the cost of a building based on a regression curve. The curve is defined by the association of dependent and independent variables obtained from historical data of buildings in a like-population sample (10:44).

Whether unit costs are developed for a group of similar buildings or for a particular category of building subsystems and whether unit costs are contained in available information sources or must be developed by regression and correlation analysis, all of the techniques have one requirement in common. Each depends on historical data from analogous experiences with flooding, in which flood costs were recorded, and from which measures of other building or subsystem variables could be obtained.

The Veterans Administration survey also identified estimating techniques which were most commonly used to achieve each level of estimating accuracy. The survey

defines the level of accuracy in terms of four purposes or stages n the estimating process (10:45):

1. Budget
2. Preliminary
3. Check
4. Final

In the budget stage approximately 82 percent of the firms surveyed used the "square-foot" unit cost technique. In the preliminary stage most of the firms began using a "partial quantity take-off" technique as soon as design sketches were available to do so. Each of the three forms of the quantity take-off technique was used for check estimates throughout the design review process, and almost all final estimates used the "complete quantity take-off" technique. The "systems-unit" and "finish unit" techniques were used consistently by a small group of proponents throughout all of the four stages (10:45).

The evidence confirms the fact that the preponderance of estimators use the "square-foot" estimating technique for the budget estimating stage. But as soon as the project becomes articulated in graphics, the estimators employ one form of quantity take-off or another (10:45).

An additional objective of the study was to establish whether any estimating technique yielded

consistently better predictions of the construction contractor's price than the others.

In comparing the predicting accuracy of the several estimating techniques, the following observations were contained in the survey.

Where the "square-foot" estimate was used, the deviation of the budget estimate from the low bid was quite high in the extreme case, and the mean deviations varied from +13 to -16 percent. The estimates made by one of the several quantity take-off techniques during the budget stage did not reflect an appreciable difference in the deviations, as compared to the "square-foot" method. The regression-analysis study demonstrated a predicting accuracy greater than conventional methods (10:47).

There were some reductions in deviations of the "square-foot" estimate for the preliminary estimate. It appeared to those who conducted the survey that as the project becomes better defined, estimators are able to select more discretely the square foot cost they believe to be reflective of the project. There was no appreciable difference in the deviations from preliminary estimates for cases where one of the quantity take-off type methods was used, compared to the "square-foot" method for the preliminary estimate (10:47).

Although the number of "finish unit" cost estimates reported for budget estimates was small, that

technique performed exceptionally well, the deviations did not exceed ± 2 percent in either the extreme or the mean. This technique also worked well for the final estimate. These findings tend to support the theory that if there are sufficient data--and the ability to discriminate between different spaces within a structure as to its finishes, peculiar needs in the mechanical and electrical trades, and fixed equipment--it is possible to have a more reliable estimate very early in the design process as well as in the final stage (10:47).

In summary, "the firms whose estimates demonstrated the best correlation to the low bid for all estimating stages reported using primarily one of the forms of the quantity take-off technique [10:51]." But the square foot method performed just as well at the budget and preliminary stages (10:51).

Most importantly, the Veterans Administration survey demonstrated that there are several possible estimating methods or combinations of methods that may provide an early prediction of flood damages. Some of these methods have been used in studies performed by research firms for the Water Resources Council of the COE.

Assessing Flood Damage

Several COE studies were reviewed which discussed benefits to be gained from flood control, but the benefits were usually defined as expected changes in appraised real

estate value of land and facilities that would result from certain water works projects. Those changes in value measure the perceived risk of flooding for both direct and indirect flood damage. In many cases, the land values benefitted from the effects achieved by other water works objectives, also, for such things as irrigation, navigation, and recreation. The following two studies reviewed, which looked directly at physical damage to facilities, strongly influenced the design of this research effort.

The Potential Flood Damage Study for Dry Creek, Goodlettsville, Tennessee (2) follows a similar approach to that proposed for this study. The authors did not evaluate specific flood protection proposals, but confined their discussion to flood damage that may occur. Anticipated damage were evaluated for the 10, 50, 100, and 500 year flood conditions. Flood damages for each flood frequency were determined for affected facilities. Assessments of structure and content values and damages thereto were established (2:6).

The major portion of the damages occurred in residential buildings. Those buildings were classified for the study according to type of construction. Content values were expressed as a percentage of structural value based on other private and governmental agency studies. Damages were based on the cost to repair structures and to replace contents at their depreciated value. Those costs were

represented as percentages of the current market value of structures and contents according to the depth of flood water above the first floor level. The percentages of structural and content damage versus depth of flooding for each type of residential construction were obtained from a separate study by the U.S. Department of Housing and Urban development.

Commercial structures were evaluated from local real estate market appraisal data, interviews, or tax assessor records. Content value estimates required on-site interviews and appraisals because of the variances in type of establishment encountered. Public facility values were obtained from sources, such as local government records and personal interviews. Due to the age and specialized nature of the facilities considered, the damage values reflected current replacement costs. The public facilities that were investigated included two highway bridges and adjacent roadways, two railroad structures and adjacent embankments, and distribution systems for gas, water, and electricity.

To relate the damages to their probability of occurrence, stage-damage curves were developed which related a total damage cost to each flood elevation. Then the total damage cost for each elevation was multiplied by the probability of that flood occurring in any given year to obtain an expected value for that flood. The expected

value of all floods below a given frequency flood were summed to obtain an expected average annual value of damages to facilities subject to flooding at that given frequency.

This method of computing an expected value is typical of the engineering economics technique described in texts such as Grant and Ireson's Principles of Engineering Economy (8:281).

Although the Goodlettsville study had a similar purpose and format to this report, it did not encounter the same type of facilities as those found on WPAFB. The Empirical Investigation of the Existence and Magnitude of a Commercial and Industrial Affluence Factor (20) by Moser and Berry dealt specifically with buildings in the commercial and industrial categories which contained facilities similar in structure and function to Air Force facilities.

COE studies normally assess the value of property and contents in an area based on projected real income figures for the area (20:iv). The purpose of the "Affluence Factors" report was to investigate the relationships among property, content, and damage values to see if those values changed over time based on changes in real income. To accomplish that purpose, the study had to predict damage costs independently of income and property market values. The study explored two sources of data which possibly could be used to construct indicators of damage

values: (1) the Federal Insurance Administration, and (2) COE flood damage surveys.

One source of information was Federal Insurance Administration data based on flood plain insurance applications and damage claims processed as part of the National Flood Insurance Program. Moser and Berry found that data had been collected since 1974 and some of the desired data were available but not in readily usable form (20:24). Their report suggested that the data source may become useful for future studies.

The second data source was COE flood damage surveys. For a particular survey to be useful to their study, it had to contain at least four important pieces of information (20:24):

1. Value of structure for each establishment,
2. Value of capital contents for each establishment,
3. Damages to capital contents for flooding above the first floor,
4. The depth of flooding above the first floor.

"In addition, this information had to be for commercial and industrial establishments whose line of business could readily be determined [20:24]."

The study obtained much of its data from flood damage surveys accomplished by the Louisville District of

the U.S. Army Corps of Engineers for establishments in the Mill Creek area near Cincinnati, Ohio.

Industries were classified into seventy-three manufacturing industries based upon the Standard Industrial Classification Manual criteria (SIC codes). The "Affluence Factor" study noted that after the surveys had been screened for containing the required usable data, the remaining sample size in any one industry code was small (20:32). Surveys from the same area were provided by the Lousiville District for this research of potential flood damage at WPAFB. Data concerning Air Force facilities were available from real property records and from record drawings of individual facilities maintained by the 2750th Civil Engineering Squadron at WPAFB. This combination of data provided a basis for a prediction of flood damage costs.

In order for the cost prediction to be useful in an economic analysis, it must be applied along with the probability of flooding occurring to find an expected value of benefits to be gained from flood protection.

The expected value of certain kinds of extreme events is an important application of probability theory in the field of engineering economy. The phrase "expected value" refers to the product of a probability and an associated monetary figure. The text, Principles of Engineering Economy (8) by Eugene L. Grant and W. Grant

Ireson, illustrates the expected value of damage as the sum of each individual level of damage multiplied by the probability that that level of damage will occur. Often the damage from an extreme event will vary with the magnitude of the event (8:286). This situation is further complicated when the probability is stated as the likelihood that the event will be equalled or exceeded. In that case, the probability that a single level of damage will occur is equal to the probability that that level of damage will be equalled or exceeded minus the probability that the next incremental level of damage will be equalled or exceeded. The total expected value of an extreme event is the sum of the expected values of each incremental level of damage that may occur as a result of that event (8:286). The tabulation of expected values from an example in the Grant and Ireson text is shown in Figure 9.

Damages D	Probability of Stated Damage p	Dp
$ 0	1.00 - 0.01 = 0.99	$ 0
250,000	0.01 - 0.005 = 0.005	1,250
300,000	0.005 - 0.002 = 0.003	900
400,000	0.002 - 0.000 = 0.002	800
Expected value of annual damage		$2,950

Fig. 9. Example Tabulation of Expected Values of Damage Due to Extreme Events (8:286)

A more general case is one in which the expected damage varies continuously with the magnitude of the flood flow. In such a case, damage can be plotted on rectangular coordinate paper as a function of flow, and the area under the curve represents the expected value of annual damages. If the relationship between damage and flow can be described by a mathematical function, the expected value may be determined by integration (8:287).

If the damage cannot be stated as a function of flood flow, then the total expected value of an extreme event must be approximated by summing the expected values of incremental levels of damage. The smaller the increment, the closer the approximation, but the overall accuracy of the approximation is determined from a combination of the degree of differentiation between damage levels, the ability to predict damage costs at a given level, and the stochastic nature of flood frequency prediction.

Chapter III explores the use of the flood prediction and estimating techniques discussed in this chapter, and develops the methodology used to analyze available data in order to obtain an expected value of flood damage at WPAFB.

Chapter III

METHODOLOGY

The purpose of this chapter is to describe the methods used to accomplish the objectives stated in Chapter I. The research was divided into three phases, each phase focused on one of the three objectives.

The first phase identified two variables, rainfall and the recurrence interval between past observed floods, which could be used in a linear regression analysis to predict flood elevation probabilities. The two variables were evaluated according to their ability to explain the variation in flood elevation frequencies, and the variable with the greatest predictive capability was used to establish flood elevation probabilities for the Huffman Basin.

The second phase identified the 500-year flood elevation, using the flood elevation probabilities developed in the first phase. That elevation contour was projected onto a map of the base, and facilities located in the area subject to a 500-year flood were identified.

Using AFSCM 173-1 as a guide, methods used in COE flood damage studies were evaluated to determine whether similar methods could be applied at WPAFB, a work

breakdown structure was established to describe the system to be estimated and to explore ways of estimating damage costs. Flood damage surveys conducted by the COE were obtained and examined to determine whether they could be used to develop estimating relationships applicable to WPAFB facilities.

The third phase developed a systematic method to associate flood damages at a given elevation with the probability that a flood of that elevation will occur to obtain an expected annual value of damages.

This chapter states the operational definitions and research questions which guided the investigation, and it explains how data for the research was gathered and analyzed. A flow chart of the research methodology is shown in Figure 10.

Flood Elevation Probabilities

The key element in analyzing the economic impact of flooding behind Huffman Dam is determining the probability of flooding at any given elevation. Without this knowledge, determining the buildings affected and a projected damage cost is not possible.

From the literature review, there are two types of methods commonly used in the field of hydrology which may be applied to predict the necessary flood probabilities. Firstly, rainfall data as predicted from the National

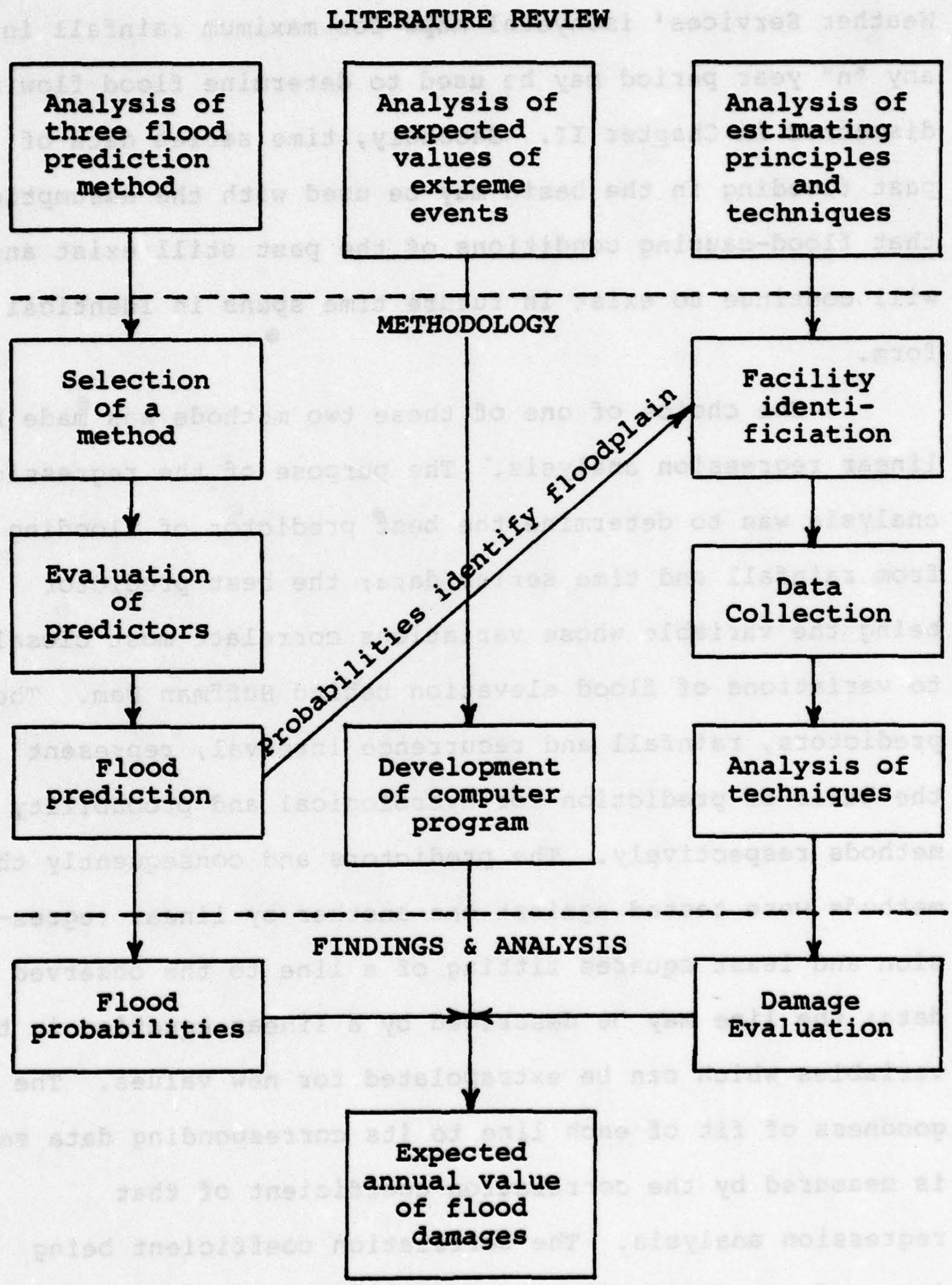


Fig. 10. Flow Chart of Research Methodology

Weather Services' isohyetal maps for maximum rainfall in any "n" year period may be used to determine flood flow as discussed in Chapter II. Secondly, time series data of past flooding in the basin may be used with the assumption that flood-causing conditions of the past still exist and will continue to exist in future time spans in identical form.

The choice of one of these two methods was made by linear regression analysis. The purpose of the regression analysis was to determine the best predictor of flooding from rainfall and time series data; the best predictor being the variable whose variations correlate most closely to variations of flood elevation behind Huffman Dam. The predictors, rainfall and recurrence interval, represent the basis of prediction for hydrological and probability methods respectively. The predictors and consequently the methods were tested against one another by linear regression and least squares fitting of a line to the observed data; the line may be described by a linear equation in two variables which can be extrapolated for new values. The goodness of fit of each line to its corresponding data set is measured by the correlation coefficient of that regression analysis. The correlation coefficient being independent of dimensions can be compared directly for the best fit and consequently the best predictor.

The dependent variable in both regressions was the elevation of flood waters behind Huffman Dam in feet above mean sea level. The independent variable in the first set of regressions was the rainfall within the watershed. Daily rainfall data was copied from the records of the Miami Conservancy District for the periods of one, three, and seven days immediately preceeding fifty recorded flood elevations. It was expected that the one-day rainfall would include the immediate runoff of a heavy short duration storm. The three-day rainfall was expected to include runoff from the farthest reaches of the watershed. The seven-day rainfall was expected to reflect the condition of runoff over a soil saturated with water from previous rains.

The twenty-four hour recorded rainfall was the smallest time period for which data was consistently available at any location. Six locations of recorded data were selected because of their geographical uniformity of distribution throughout the watershed and the availability of rainfall data for the fifty storms examined. These six locations were Huffman Dam, New Carlisle, Springfield, Urbana, Bellefontaine, and St. Paris. The arithmetic mean of the rainfall at the six locations was also used as a regressor.

The data was assembled in a computer file and regression analysis performed using SPSS Subprogram

REGRESSION (21:320). This was also done with the time series data using the log of the recurrence interval to linearize the data. Selection of the variable with the regression coefficient whose absolute value was closest to unity was then made, which was the time series data as presented in Chapter IV.

Discussing this result with Mr. Rozelle, Assistant Chief Engineer for Flood Control of the Miami Conservancy District, he proffered the possibility that the fifty-five year Huffman Dam operations record does not reflect the same times series which would have been reflected using pre-1922 calculations. The pre-1922 calculations of what the flood elevations would have been during great storms in the nineteenth century had the dam been built were calculated in 1920 by MCD engineers using Kutter's Formula as detailed in Chapter II.

Values obtained by this method were tabulated for 1893-1917 (33:335) and a regression analysis of time series data for those floods was performed in the same manner as was performed for floods recorded after 1922. The results were compared by plotting regression lines obtained for both on the same graph, calculating the 99.9 percent probability value of both lines and testing for common regions on the graph. It was determined the calculated data should not be included, and a linear

equation based on the 1922-1977 operating record was to be the basis of probability determination.

The regression analysis of this data resulted in a linear equation approximating the variation of the variable "E" flood elevation in relation to "R" recurrence interval:

$$E = B \log_{10} R + A$$

where "A" and "B" are constants.

The inverse of this equation is as follows:

$$R = 10^{\left(\frac{E-A}{B}\right)}$$

and probability P = 1/R, may be substituted as follows:

$$P = 10^{\left(\frac{A-E}{B}\right)}$$

Using these equations, the likelihood of flooding at given elevations was determined by solving for the recurrence interval "R" or the probability of occurrence "P." Working in the other direction, given the 100 or 500 year recurrence intervals for which flood plain planning is required, the elevations "E" were determined so that affected facilities could be identified.

Damage Estimation

The second phase of the research identified facilities subject to flooding and explored ways of estimating damage costs to those facilities. The estimating principles contained in AFSCM 173-1 were used as a guide to accomplish the analysis of damage costs.

The first task in the estimating process described by the AFSCM 173-1 was determining the purpose of the estimate and describing the system to be costed (6:2-1,2-2). In accordance with the research objectives stated in Chapter I, the purpose was to provide direction to the initial evaluation of the potential flood hazard and to the selection of alternatives for flood protection. In terminology suggested by AFSCM 173-1, the estimate was a study leading to a decision on possible changes in the facilities management program (6:2-1). The estimate required, at most, a "preliminary" or "budget" level of accuracy (10:45).

The system of facilities is comprised of the various identified structures and the utilities and services distribution networks which connect to them. The term "facility" is used here in the broad sense of Air Force real property accounting to include distribution systems as well as individual building structures. The primary utilities are gas, water, sewer, and electricity. "Services distribution" is a term used here to refer to

such things as roads, sidewalks, and railroads which serve the various structures in much the same way as utility systems.

The system of facilities exists in an environment that is subject to flooding, and the output of that system is affected by the damage that flooding causes. Inputs to the system are actions taken by management to protect or restore the function of the facility when flooding occurs. The output of the system then is the ability of the facility to serve that function. As stated in Chapter I, the evaluation of importance of the function to the base mission was beyond the scope of this research, but the cost of actions required to restore a facility's function are a measure of direct flood damages.

The effects of flooding on the system are determined largely by the type of flooding expected in the area. WPAFB is protected from torrential flooding of the Mad River by a dike constructed along the east bank of the river, so flood waters impinging on base facilities are due solely to ponding behind Huffman Dam. Flood damage is due to waters infiltrating into facilities as it rises around them. Dynamic forces on structures, erosion, and deposited debris, while still present, are reduced from that which one would envision for most floods.

The cost of actions taken in advance to protect a facility from possible flooding would be considered as the

cost of a proposal in an economic analysis. The cost of actions that would be taken after flooding to restore the function of a facility would be a measure of the flood damage effects or avoided costs in an economic analysis.

The system was further described by the data that was collected on the components and by the estimating structure[10] established.

The second task in the estimating process was selecting the estimating structure (6:p.2-4). That structure was guided by the availability of data, the purpose of the estimate, and the methodology used to achieve that purpose. The "preliminary" level of accuracy required for the stated purpose allowed a high-level of aggregation of cost elements in the work breakdown structure. Further restrictions on the level of aggregation depended upon available data and applicable methods.

The approach taken in this research effort was to begin with the characteristics of highly aggregated components of the WPAFB facilities system and attempt to develop estimating relationships through the analysis of other flood damage studies and the application of construction estimating techniques. The level of aggregation was then reduced as necessary to further describe the

---

[10]Estimating structure: A framework for collecting and analyzing data concerning cost elements of the system; the work breakdown structure (6:p.2-4).

system and to incorporate additional data needed to define relationships.

The following research questions guided the investigation:

1. What are the 100-year and 500-year flood elevations, which define the flood plains governed by EO 11988 and DOD instructions?

2. What are the WPAFB facilities located in the flood plain?

3. What factors need to be considered in estimating the cost of damage to specific facilities?

4. How can estimating techniques be applied to evaluate potential flood damage at WPAFB?

To identify those facilities within the scope of our study, the 500-year flood elevation identified by the probability analysis was projected onto a topographical map[11] of the base, and all numbered structures contained within that contour were pointed out. The map used was the WPAFB Map of Areas A, B, and C, drawing numbers DEEE-D with latest revision of January 1976. A field reconnaissance of the base was conducted to correlate the flood profile with field identifiable features, to update the

---

[11] Topographical map: A map on which are represented the surface features of a region, including hills, valleys, rivers, bridges, roads, structures, etc.

area map, and to verify that no facilities within the contour had been overlooked.

The record drawings of the identified facilities were examined to obtain the finished floor elevation of each facility. To allow for possible error in plotting the 500-year flood elevation contour on the map, the elevations of several facilities outside but near the contour were also checked to verify that, in fact, their finished floor elevation was above the 500-year flood elevation. To obtain elevations that were not located in the record drawings, unknown floor heights were measured from known elevations using differential leveling[12] techniques.

The third estimating task was collecting, evaluating, and applying cost related data describing components of the facilities system (6:p.3-1). After facilities subject to flooding were identified, the following data was collected to describe facility characteristics relevant to the study. Record drawings of each structure and real property records in the WPAFB Civil Engineer's (BCE) files were reviewed to obtain available data. Data was selected because they either described the materials and construction details which may be susceptible to flood

---

[12]Differential leveling: A surveying technique in which the height of a level instrument above a point of unknown elevation is compared to the height of the instrument above a point of known elevation to ascertain the unknown elevation.

damage and may require repair, or they described characteristics that may correlate with variables used in other flood damage studies to predict system behavior. The data collected was entered in a data file for later use in the damage/cost analyses.

Data gathered from record drawings included the first floor elevation, type of foundation, type of structural system, height of walls, and number of floors for each building.

The first floor elevation, in addition to its earlier use to identify affected facilities, was used in the damage analysis as a point of reference to relate a predicted flood elevation to a water level at the structure. The type of foundation and type of wall structure were used to classify structures into categories susceptible to varying types or extents of damage. The height of walls and number of floors data became important in determining extent of damage as water levels exceeded the first floor elevation.

Data obtained from BCE real property listings included the current use of the structure, the gross area in square feet, year completed, and real property construction cost and replacement value of the structure.

The current uses of the structures were again used along with construction types to classify structures according to susceptibility to damage, this time primarily

considering damage that may occur to building contents. The gross area, year completed, construction cost, and replacement value were obtained in order to investigate their use as independent variables to which flood damage costs could be related.

Real property construction costs are those costs that have been capitalized to a facility account in real property records. They include the original construction cost and the cost of any remodeling or modification projects which change the capital value of the structure (AFM 87-1). Replacement value represents an estimated cost to completely replace the structure. It is obtained by multiplying the construction cost by a factor based on the year that original construction was completed. The factor increases the real property construction cost figure to account for inflation and changes in construction technology which have taken place since the original structure was completed. Replacement cost information was obtained from the Real Property Replacement Value listing, report code PCN 001-283 as of 30 September 1978.

With this data available a work breakdown structure could be tentatively proposed to guide the collection of further data and to define the level of aggregation at which the application of various estimating methods could be analyzed.

At the highest level of aggregation, the work breakdown structure was classified according to the general segments of the facilities system described earlier, e.g., buildings and utility and service distribution networks. Corps of Engineers flood damage studies were reviewed to observe how these segments were addressed in their research.

The studies used were those that had been performed in developing flood control programs for the Ohio River System (28), the Upper Colorado River System in Utah, Arizona, Colorado, and New Mexico (26), and the Alabama-Coosa River System (22). The focus of the review was to evaluate the comparability of the studies to determine in what ways analogies could be drawn to the WPAFB situation. It was found that the larger COE studies were directed toward an even higher level of aggregation. Only the two studies reviewed in Chapter II were conducted at a level that could be useful in developing a method of assessing potential damage to existing facilities. The findings concerning flood damage studies for large systems and their implications to the estimating process are discussed in Chapter IV.

At a lower level of aggregation, individual buildings were classified into categories using alternative classification schemes. This was done to determine whether groups of buildings with common characteristics

could be identified which were analogous to categories of buildings involved in other flood damage studies and which contributed significantly to the flood damage risk at WPAFB.

Emory describes the coding process as follows:

> This mapping of data onto a limited number of [nominal] categories sacrifices some of the data detail but is [sometimes] necessary for efficient analysis [7:339].
>
> This [nominal] scale is especially valuable in exploratory work, the objective of which is to uncover relationships rather than secure precise measurements. . . . Cross-partitions of these . . . factors can provide insight into important data patterns [7:114].
>
> Four major rules should guide the establishment of category sets. Categories should be [7:339]:
>
> 1. Appropriate to the research problem and purpose.
> 2. Exhaustive.
> 3. Mutually exclusive.
> 4. Derived from one classification principle.

The variable building characteristic expected to most directly influence the building's susceptibility to flood damage was the type of construction, but most COE studies reviewed classified buildings by their use. So both of those classification schemes were used.

Building construction types are basically masonry, woodframe, and metal, but the classification scheme could be expanded to recognize specific combinations of structural types as long as each of those combinations identified a representative block of buildings. For example, a group of buildings could be described as made of concrete

block masonry units on concrete slab, or another group as brick masonry units with a basement, etc. To begin with, the basic three category classification was established and examined to determine whether a further breakdown would be possible or useful. The data file for each building was coded as follows:

1. Masonry
2. Metal
3. Wood
4. Other

The fourth category was established to accept structure other than buildng which could be placed in one of the first three categories.

Basic types of building activities into which Air Force facilities may be grouped under the classification system used by COE studies are industrial and commercial but the classification, again, could be expanded to identify common Air Force activities.

The initial classification was intended to be compatible with the COE classification scheme. It was suspected that the difference between industrial and commercial facilities was drawn along the lines of manufacturing versus sales, and would provide an indication of differences in susceptibility to flood damage. Manufacturing facilities were expected to contain heavy equipment, stocks of raw materials, and durable, easily cleaned

interior finish materials in some sort of process layout configuration. Commercial facilities were expected to contain office equipment, stocks of finished materials, and more decorative interior finish construction materials in areas of high customer traffic.

Air Force activities were defined as industrial or commercial as follows:

1. Industrial

    Maintenance shops

    Research laboratories

    Utility equipment shelters

    Other process activities

    Warehouses

2. Commercial

    Administrative offices

    Flying operations offices

    Recreation centers

    Other business/office activities

The facility use data was collected in the form of the six digit facility utilization codes of the Air Force real property accounting system. The data was recorded in the data file under the first three digits of that code as follows:

Code	Use
12X	Petroleum handling facility
13X	Navigation aids
14X	Flying operations facilities
17X	Training facilities
211	Maintenance hangars
214	Vehicle maintenance shops
216	Ammunition maintenance facilities
217	Service equipment shops
218	Aerospace ground equipment shops
219	Base civil engineering maintenance shops
229	Liquid oxygen generation facility
310	Electronics and aircraft research and testing facilities
422	Munitions storage
442	Hazardous storage and general warehouse space
610	Administrative facilities
730	Security police facilities
740	Miscellaneous recreation facilities
750	Golf club facilities
811	Electrical power stations
84X	Water supply and pump stations
890	Electrical utility vaults

After the data concerning base facilities was obtained and a work breakdown structure was established, the WPAFB data was compared to the information contained in COE flood damage surveys to see if similarities existed which would allow estimating relationships to be drawn from these analogous systems to predict flood damage. The areas in which similarities were sought included the type of

construction, size (gross area), type of use, and capital costs of the facilities.

Flood damage surveys conducted by the COE in the Mill Creek area near Cincinnati, Ohio, were obtained from the Louisville District. The surveys were evaluated for usability according to the criteria of comparability, quality, and relevance contained in AFSCM 173-1.

Comparability of the two facilities systems was tested by determining whether data was uniformly defined over both systems such that facilities in both systems could be mapped into a common classification scheme.

The quality of the data was tested by evaluating the consistency of the data collection techniques that were used. Consistency depends on whether the standards used to assign data values were constant throughout the data collection process (7:304).

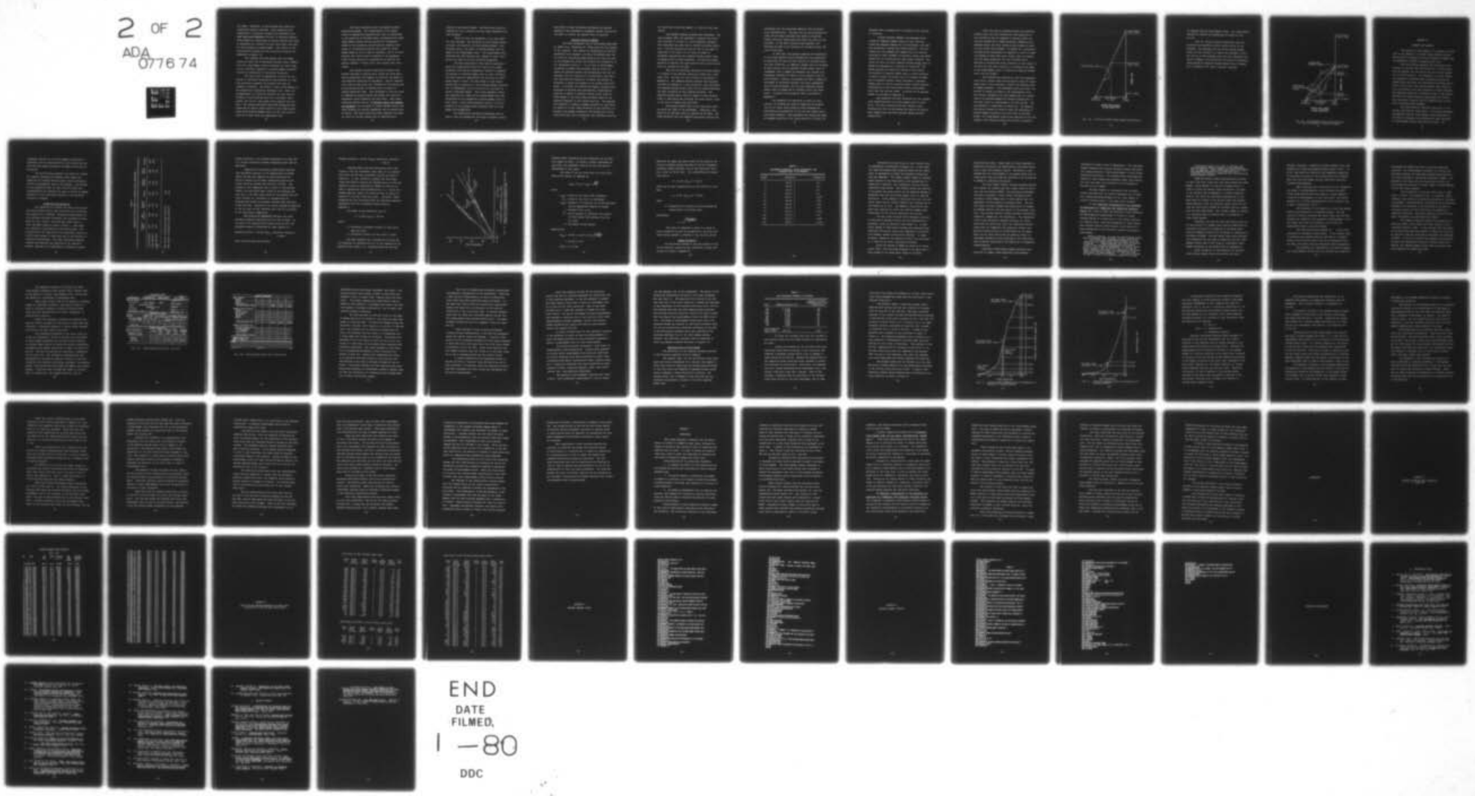
The relevance of the data was evaluated by discussing ways that the data could be used in developing cost estimating relationships and then testing the data to determine whether a relationship did, in fact, exist.

Since Moser and Berry (20:iv) had encountered problems in using data from the flood damage surveys which limited the sample sizes in their statistical analysis, it was expected that some data would not be usable. But this research was not concerned with time trends and was not confined to categorizing the establishments by specific

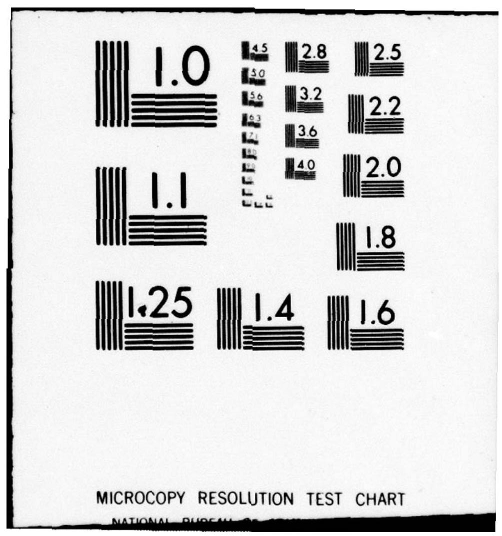
AD-A077 674 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL--ETC F/G 8/8
ANALYSIS OF POTENTIAL FLOOD DAMAGE AT WRIGHT-PATTERSON AIR FORC--ETC(U)
SEP 79 P F QUINN , J W WIMBERLEY

UNCLASSIFIED AFIT-LSSR-24-79A NL

2 OF 2
ADA 077674



END
DATE FILMED
1 -80
DDC


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
MICROCOPY RESOLUTION TEST CHART

SIC codes. Therefore, it was believed that sufficient usable data could be obtained. Once categories were established a correlation analysis was performed using SPSS subprogram REGRESSION (21:293) to determine whether flood damage as a percentage of overall capital cost could be estimated as a function of water level above the floor for each category of establishment. The results of the classification process and the correlation analysis are presented in Chapter IV.

The findings were that damage costs for WPAFB facilities could not be determined through direct correlation with flood damage surveys conducted for other areas. It was, therefore, necessary to develop damage estimates through the examination of individual structures.

The third level of aggregation involves the surveying of individual buildings by base personnel to identify structural elements and contents that might be damaged by flooding. The extent of that survey depends on the construction estimating techniques used. While the accomplishment of a detailed estimate for each level of flooding in each building would be a formidable undertaking, the use of a cost model could simplify this process. The various previously described estimating techniques may be used to assign values to cost model parameters which describe damage costs for each facility as a function of water level and replacement cost.

The fourth estimating task was applying proper estimating methods. The investigation of two higher levels of aggregation discoverd that, due to limitations in the usability of available data, correlation with other flood damage studies did not provide the information needed to use regression and correlation analysis techniques or to develop historical unit costs for flood damage based on size or type of building. But it is still possible that costs could be analyzed in an economical study through the use of a combination of "partial and modular takeoff," "finish unit," and "system unit" techniques.

The process involves identifying building components affected at varying water levels and using engineering experience and judgment to envision the damage to the respective materials and equipment. Partial takeoffs could then be made using cost information from catalog and pricing guide sources to develop costs to repair or replace specified items. Cost developed in this way could be combined to develop finish and system unit costs for components found throughout the facilities. Some repair estimating guides such as the <u>National Repair and Remodeling Estimator</u> (23) by Albert S. Paxton provide finish unit costs directly for certain components such as drywall partitioning. The costs could be further combined into modular costs for certain spaces such as administrative

offices or maintenance shops. And those costs could be combined in turn to develop the cost model parameters for each building.

There are four key parameters in the cost model for each building: the elevation at which damage begins to occur, the elevation at which maximum damage to the building occurs, the extent of maximum damage, and the shape of the stage-damage curve. The stage-damage curve describes the cost function with respect to water level within the range of the two elevation parameters.

The data collected for each facility provided a basis for establishing values for three of the model parameters with certain assumptions required to complete the process of relating damage costs to water elevation. The floor elevation approximated the elevation at which damage began to occur, the eave height or roof height established an elevation at which maximum damage occurred, and the replacement costs of the facility provided the extent of maximum damage. These three parameter values were adjusted up or down and the stage-damage curve was established by the assumptions relating damage costs to water level. Using these parameters values, an initial estimate of the average annual expected value of flood damage was accomplished.

The construction estimating techniques must be used to test the assumptions and adjust parameter values.

The extent to which estimating techniques are applied depends on the refinement of parameter values required for the model to achieve the desired level of accuracy.

Expected Value of Damages

The fifth estimating task in the process described by AFSCM 173-1, documentation, constituted the third phase of the research. The reasons for documenting the factors considered in an estimate, the data and methods used, and the areas of uncertainty experienced are so that the user of the estimate can verify the validity and reliability of his information (6:p.6-1). In the case of flood damage estimation at WPAFB, base planners need to be able to repeat the analysis quickly and economically and with the assurance that the results will be consistent over time. They also need the capability to modify the methods as necessary to adjust for changes in the system being estimated. To provide this flexibility computer programs were developed to describe each mathematical transformation required to equate an expected average annual value of flood damage to any given flood elevation based on the expected frequency of that flood occurring. The programs were designed to compute a damage estimate for each facility based on a given flood elevation at that facility, to multiply that damage estimate by the probability of that flood occurring, and to accumulate that expected value for

all facilities sustaining damage in a flood of that elevation.

Two FORTRAN language programs were developed. The first program, COST, was designed to identify the buildings involved in a flood of a given expected frequency. The flood plain was used only to identify affected facilities. Then the program provided an idea of the order of magnitude of the flood risk in terms of number of buildings involved and the expected average annual value of damage costs to those buildings. The program allowed planning to consider the flood hazard within a given flood plain as required by EO 11988.

Data for the buildings identified as being subject to flooding in the 500-year flood were loaded into a computer file. The data for each building is presented in Appendix B. The computer program selected the buildings involved by flooding at a given elevation, then calculated the expected average annual costs for all floods exceeding the floor elevation of each affected building. The expected average annual value of damage to each building aided in identifying key buildings for which further study of the risk of flooding was justified.

The program worked from a given recurrence interval which was input by the programmer. Typically, this would be the 100-year flood as required by EO 11988. The flood elevation with the expected recurrence interval was

calculated with the regression equation from the probability determination. The data file for each building was read, and the floor elevation was tested to determine whether the given flood would rise above the floor of the building. If the floor elevation was exceeded, the building was said to be involved with flooding within the given flood plain.

In that case, the program computed the probability of the flood elevation being exceeded and the probability of occurrence of each one foot interval of flooding above the floor elevation, it computed a damage cost for flooding at each interval and an expected average annual value of thatdamage, and it summed the expected cost figures over succeeding intervals to obtain a total expected cost for each building. Finally, the program provided a summary of the number of buildings involved, the total replacement cost of those buildings, and the total expected average annual value of damage due to flooding within the flood plain. A listing of the program, COST is provided in Appendix C.

The probability of occurrence of each one foot interval of flooding was found by computing the probability of the lower bound elevation being exceeded and subtracting the probability of the one foot higher elevation being exceeded. That probability was multiplied times the damage occurring at the flood elevation to obtain the

expected value of damage due to flooding at the interval of elevation.

A second program, ANCOST, was developed which, instead of computing damage costs for each facility, traced the expected damages for all buildings in the 500-year flood plain through each flood elevation. The difference was that damages were summed over all involved buildings at each increment of elevation rather than being summed over all elevations for each single building. The result was that the total expected average annual value of damage was expressed as a function of elevation. The second program was useful for looking at the overall relationship of expected damage costs to flood elevation in order to weigh the overall risk of flooding at WPAFB and to determine whether sudden increases in expected damage costs at certain elevations might justify specific consideration of the flood hazard within flood plains other than the 100-year flood. A listing of the program, ANCOST, is provided in Appendix D.

Both programs initially contained the four assumptions described earlier to relate damage costs to water level. The floor elevation and eave height of each building were read by the program and used as the points where damage began and where maximum damage occurred respectively.

Since the type of flooding studied was caused by ponding only, and since differential settlement due to soil saturation was not expected to greatly affect the concrete foundations of WPAFB buildings, damage was not expected before the floor elevation was reached or after the eave height was exceeded. If damage for a particular building being investigated is expected to start or reach its maximum at some other point within those two bounds the cost model parameters for that building can be modified by changing the floor elevation or eave height in the data file for that building or by changing the shape of the stage-damage curve to reflect the expected damages within the two bounds.

The programs were modified so that the programmer could enter a factor which was multiplied times the replacement cost of the buildings to adjust the maximum extent of damage parameter. The programmer could also enter two factors to change the shape of the stage-damage curve. The original assumption was that damage cost as a percentage of the maximum damage was directly proportional to the water level as a percentage of the eave height. The relationship is illustrated in Figure 11a. By changing the factors entered to raise or lower the percentage of maximum damage incurred in the first half of the eave height, the stage-damage function was depicted as two line segments with differing slopes which could be adjusted

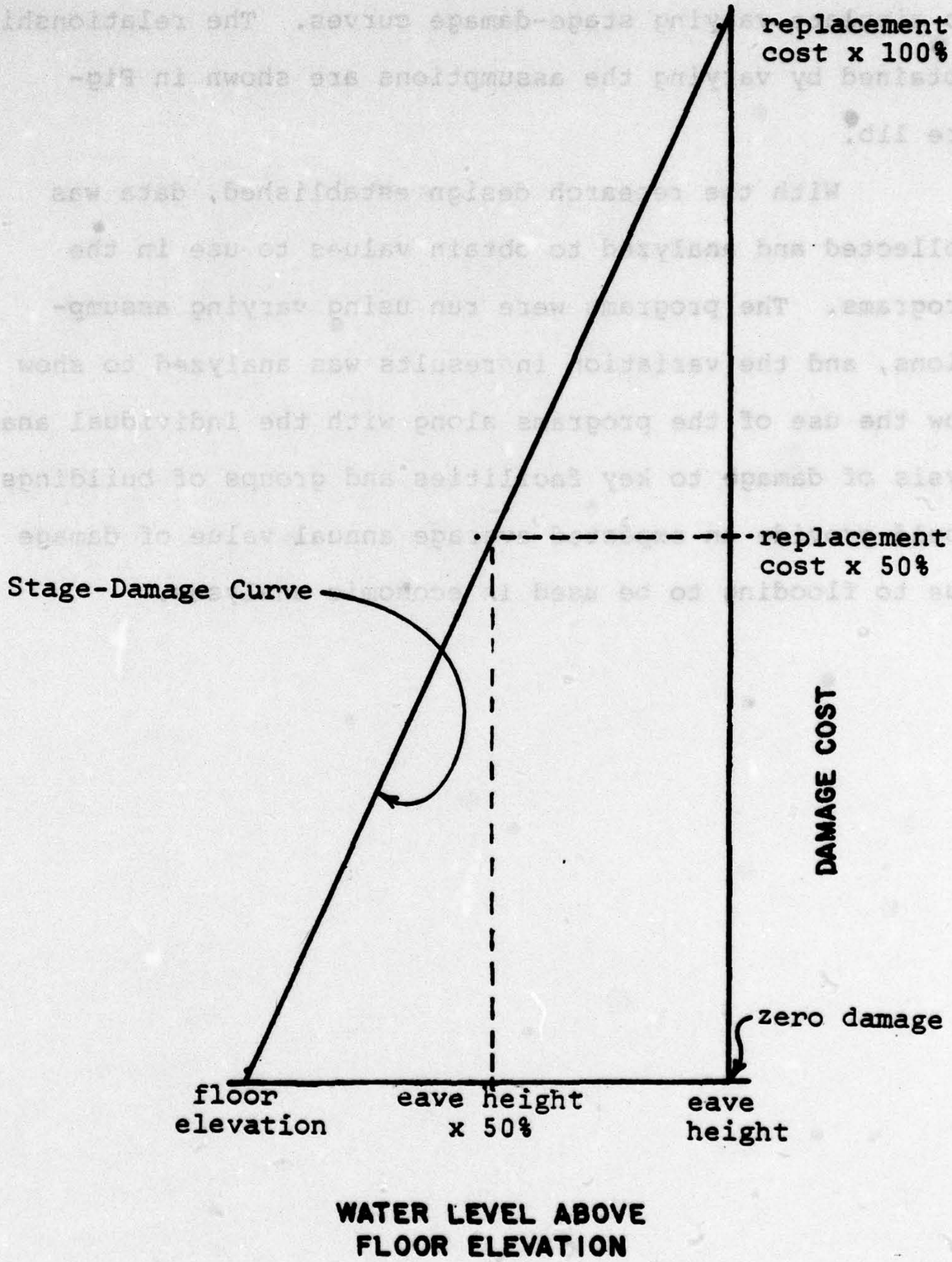


Fig. 11a. Initially Assumed Stage-Damage Relationship

to simulate varying stage-damage curves. The relationship obtained by varying the assumptions are shown in Figure 11b.

With the research design established, data was collected and analyzed to obtain values to use in the programs. The programs were run using varying assumptions, and the variation in results was analyzed to show how the use of the programs along with the individual analysis of damage to key facilities and groups of buildings would provide an expected average annual value of damage due to flooding to be used in economic analyses.

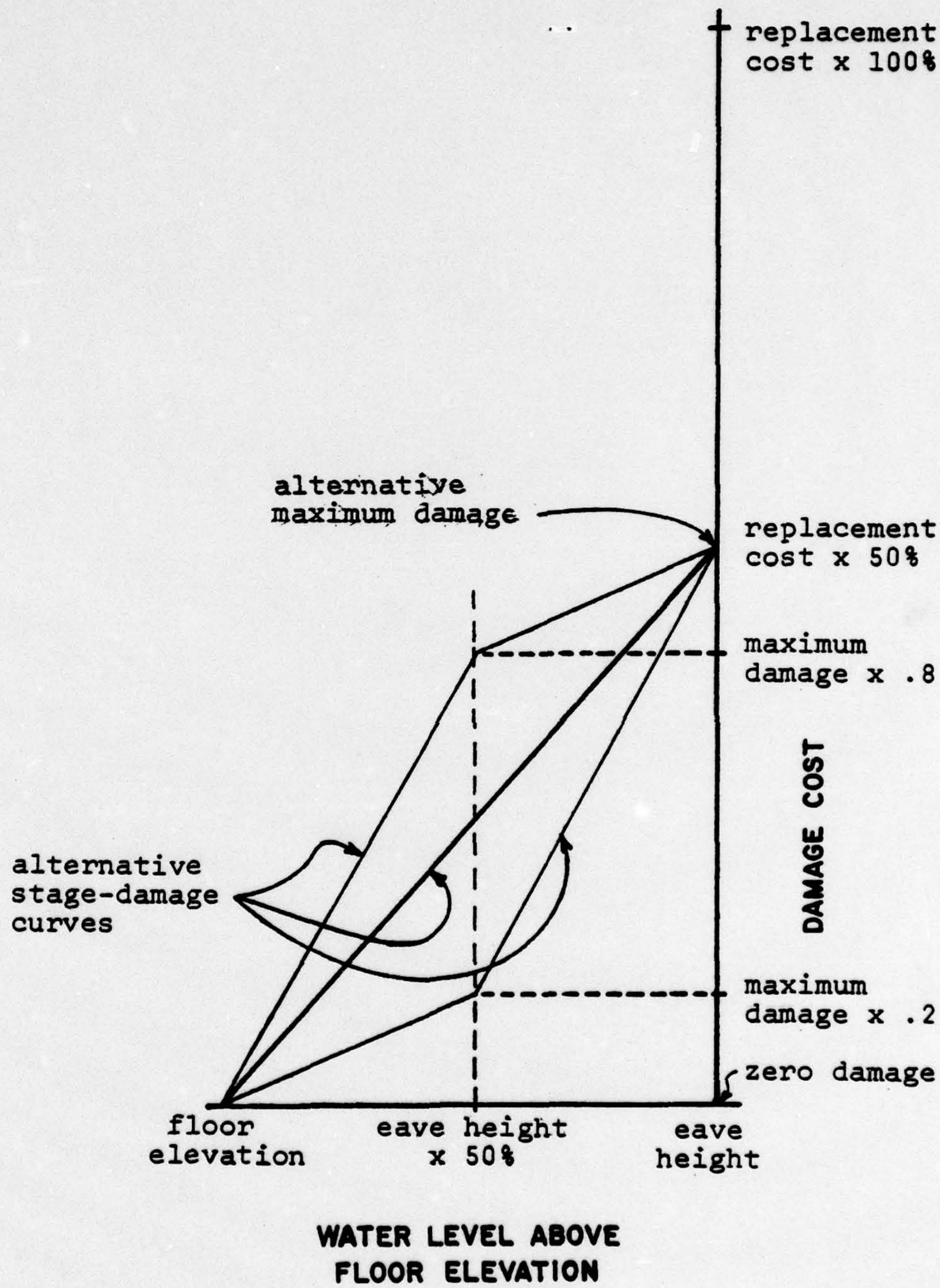


Fig. 11b. Stage-Damage Relationships Modified by Factors entered in Computer Programs

CHAPTER IV

FINDINGS AND ANALYSIS

The purpose of this chapter is to present the findings of the research, to analyze those findings as they may be used to evaluate the risk of flooding at WPAFB, and to demonstrate a method of assessing that risk.

The first section compares the correlation coefficients of rainfall and time series data to flood elevation and selects the time series data as the best predictor of flood elevation. The difference in linear regression equations using data from calculated and observed floods before and after the construction of Huffman Dam is shown, and the data from observed floods after construction is selected as the best predictor of flood elevation. The regression equation for observed flood is then used to determine the flood elevations associated with given N-year recurrence intervals and the probabilities of given flood elevations being exceeded.

The second section identifies facilities in the 100-year and 500-year flood plains. The section describes the approach taken by flood damage studies performed by the Corps of Engineers, and evaluates the data contained in flood damage surveys conducted by the COE. The

regression analysis of the flood damage survey data is presented, and the implications that the surveys and studies had upon damage estimation for WPAFB facilities are discussed.

The third section presents the results of running the computer programs and analyzes those results by comparing the expected average annual values obtained by varying the parameters used by the programs. The effects of the assumptions made for each trial are shown and recommendations are presented of ways to refine the damage estimation by the individual analysis of key buildings affected by flooding.

Probability Determination

The comparison of rainfall and time series regression data strongly favors time series data for predicting the probability of flooding. Regression coefficients for six locations scattered throughout the watershed as determined for one-, three-, and seven-day totals prior to fifty recorded floods are shown in Table 3. Also shown are regression coefficients for time series data. The correlation of the logarithm of the recurrence interval at 0.996 is much closer to unity than any of the rainfall to elevation relationships. The lower correlation between rainfall and elevation was explained by Dr. Ronald G. Schmidt, Chairman of the Department of Geology at Wright

TABLE 3

CORRELATION COEFFICIENTS OF POSSIBLE FLOOD PREDICTORS

	Huffman Dam	New Carlisle	Spring-field	Urbana	Belle-fontaine	Saint Paris	Average
7 Day Rainfall	.355	.385	.414	.367	.339	.288	.385
3 Day Rainfall	.776	.706	.797	.820	.660	.829	.846
1 Day Rainfall .657	.629	.476	.483	.514	-.059	.459	
Time series of measured floods 1922-1977				.996			
Time series of measured floods 1893-1917				.915			

State University in an informal conversation as being due to a strong interaction between underground water and the Mad River.

Comparison of correlation coefficients obtained from regression analysis of the observations of floods behind the dam were compared to those calculated by Kutter's Formula by the Miami Conservancy District for storms occurring between 1893 and 1917 (33:335). The purpose of this comparison was to assist in determining whether the calculated great floods of the nineteen century were of the same times series as the observations and could increase our confidence in extrapolating the observed data beyond the maximum recorded flood elevation of 809 feet MSL. Analysis of the linear regression equations of the two sets of data indicated that they do not belong to the same general population.

SPSS Subprogram REGRESSION indicates two quite different equations describing the two sets of data. In the case of the observed data between 1922 and 1977 the regression equation determined by least squares is:

$$\text{Maximum elevation} = 10.366\ [\log_{10}\ (\text{recurrence interval})] + 789.99$$

while the calculated data yields:

Maximum elevation = 20.646 [$\log_{10}$ (recurrence interval)]

+ 792.05

Plotting these lines and calculating their prob values to the .001 confidence level there is no intersection until the 100 year recurrence interval as shown in Figure 12. It was, therefore, assumed that data calculated from Kutter's formula for flooding prior to 1922 was subject to error as described in Chapter II and was not used in calculating flood probabilities, i.e., use of the formula does not reflect the existing state of nature as observed in the past fifty-five years. Therefore, flood probabilities were calculated from the regression equation determined from the 90 observed events listed in Appendix A.

The simple linear regression line is:

$$E = 10.366 \log_{10} R + 789.99$$

where:

E = elevation of probable flooding in feet above mean sea level.

R = recurrence interval of that flood in years.

The above equation has a probability of being the true equation of regression of 0.5, if all elements of the populaton were known; i.e., flooding behind the dam were

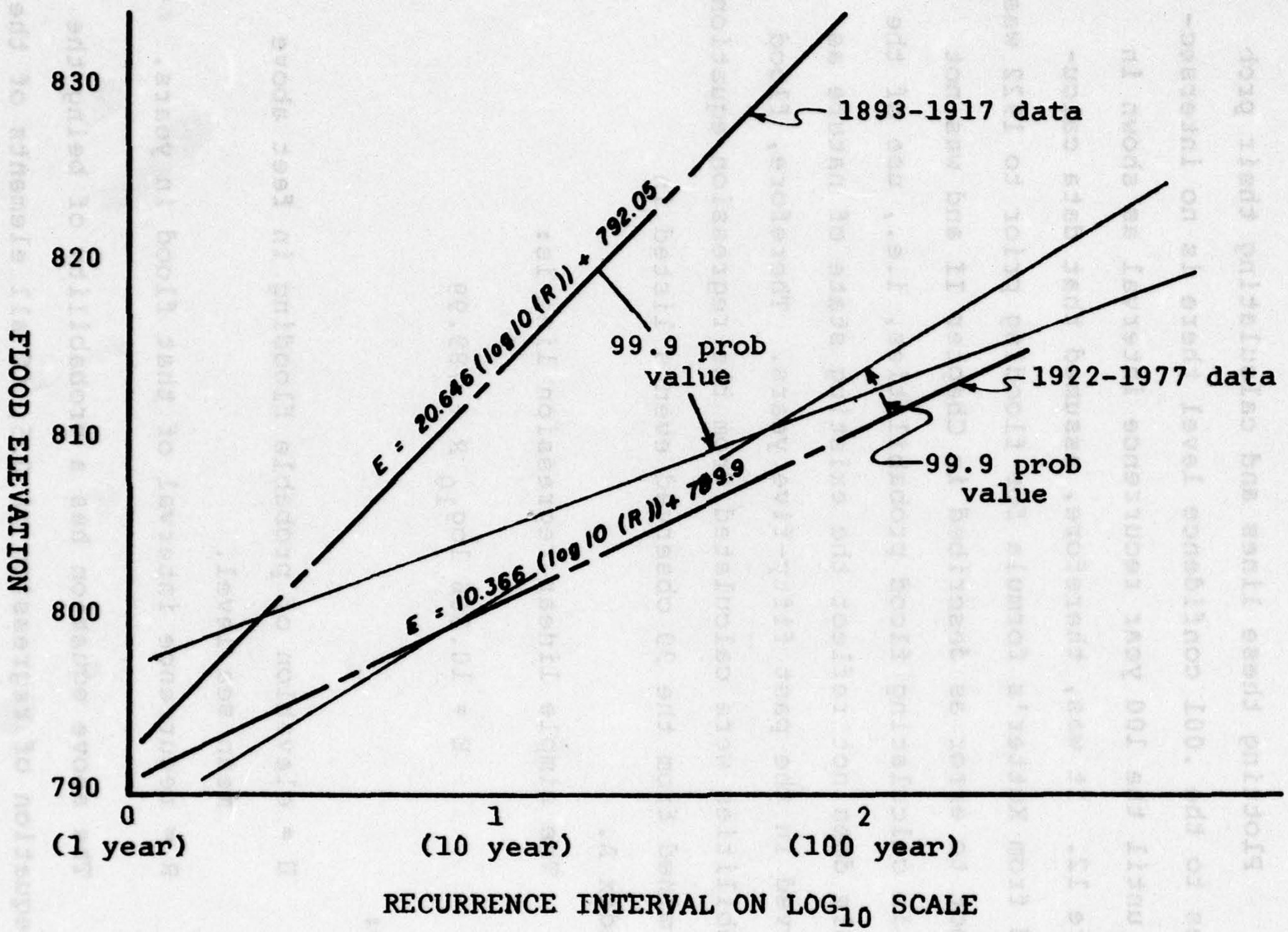


Fig. 12. Comparison of Regression Equations for Data from Floods Occurring Before and After 1922

observed under unchanging natural conditions for an infinite number of years. To obtain a greater confidence of say 0.999, the confidence interval of the line must be established at that level.

The slope of the two lines which the true line's slope falls between is computed as:

$$B_{.999} = B_{.5} \pm t_{.999}\, \sigma \sqrt{\frac{\Sigma X^2}{n}}$$

where:

$B_{.999}$ = slope of line with 0.999 confidence

$B_{.5}$ = slope of line with 0.5 confidence

$t_{.999}$ = Student's "t" statistic for 0.999 confidence and the appropriate degree of freedom

σ = standard error at $B_{.5}$

X^2 = sum of squares of residuals (the amounts by which actual data deviates from the $B_{.5}$ line)

n = the number of data points.

Substituting:

$$B_{.999} = 10.366 \pm (4.073)(0.247) \sqrt{\frac{4.8034}{17}}$$

$$= 10.366 \pm 0.535$$

$$9.831 \leq B \leq 10.901$$

These are the upper and lower limits of the slope of the line as it passes through the mean of the two regression variables (flood elevation, log of the recurrence interval), which is 789.65 feet. This establishes the regression line at

$$E = 10.901 \log_{10} R + 789.65$$

Since the one year probabilities are the inverse of R we have

$$E = 10.901 \log_{10} 1/P + 789.65$$

where

P = probability of elevation E being exceeded by flood waters in any given year

Rearranging,

$$P = 10^{\left(\frac{789.654-E}{10.901}\right)}$$

This data is tabulated in Table 4 in terms of N-year probabilities and the probability of any given elevation being reached or exceeded in any one year period.

Damage Estimation

The facilities located in the area subject to the 100 and 500-year floods and data collected on those facilities are listed in Appendix B.

TABLE 4

RECURRENCE INTERVALS, FLOOD ELEVATIONS, AND PROBABILITIES OF OCCURRENCE

N-Year	Elevation	Probability
1	790.33 3	1.0
2	793.29 3	0.5
5	797.27 3	0.2
10	800.53 5	0.1
15	802.47 5	0.067
20	803.83 8	0.05
25	804.89 9	0.04
50	808.17 2	0.02
75	810.09 1	0.013
100	811.45 5	0.01
200	814.74 7	0.005
500	819.07 1	0.002

Considering the facilities at their highest level of aggregation as described in Chapter III, it was found that many COE studies were directed toward an even higher level of aggregation in which the facilities system was only one component. The larger studies looked at regional areas ranging in size from entire river systems down to commercial, industrial, and residential districts within identified flood plains. The studies defined the benefits to be gained from flood control as the expected changes in appraised value and real estate market value of land and facilities. Direct damage to facilities was only one cost factor among various indirect affects that flooding has on the economy of an area. The damage to distribution networks were absorbed by direct and indirect damage costs associated with the various facilities they served.

The only study reviewed which addressed utilities or distributin systems directly was the Goodlettsville, Tennessee, study of potential flood damage (2). In that study, damage to distribution systems was considered when individual structures, which were components of distribution systems, became involved with flooding. In those instances, damage to the affected structure was estimated as it would be for other individual buildings.

Since the systems at WPAFB are often at or below ground level, they have been designed to be impervious to water except at the nodes where branch or terminal

connections are made. Those nodes are often enclosed in protective structures and identified as individual facilities in base real property records. Therefore, it was assumed that any flood damage to the system would occur at those points, and the study was confined to the estimation of damage at individual structures.

The flood damage studies reviewed provided average cost figures for larger areas and a wider range of activities than are found at WPAFB. The estimating techniques used were to develop a "cost-to-cost" estimating relationship of flood damage cost to known capital cost for components of each respective economic sector. The studies often tied their damage cost predictions to indexes of economic activity for each sector of the economy in an area. The economic sectors studied included agricultural, industrial, commercial, and residential. The "Goodlettsville" study contained a separate category for public structures and activities, while the "Affluence Factors" study broke the commercial and industrial sectors into separate classifications of establishment by SIC codes. While all Air Force facilities are publicly owned the individual character of the buildings in the flood plain would be better described by the industrial or commercial classifications.

Individual establishment damage estimates were used only to support those estimating relationships

developed at higher levels of aggregation. The individual damage estimates were usually obtained through interviews with representatives of each establishment or from similar specialized estimates. The studies merely referenced the sources of their supporting estimates rather than showing how they were made, thus providing little guidance on methods to use in WPAFB.

The main element of information that the major studies performed for the Corps of Engineers had to offer were average estimated damages for the large number of diverse buildings found in the large areas surveyed.

In their _Empirical Investigation of the Existence and Magnitude of a Commercial and Industrial Affluence Factor_ (20), David A. Moser and Charles A. Berry discussed the advantages and disadvantages of trying to relate average figures of a larger area to the unique situation of a smaller area. They were attempting to relate aggregate national capital growth figures to the growth in a local economy and to the resulting increase in potential flood damage.

> Several problems, in using the flood damage survey data to estimate local economic trends, were noted. . . . Two of the most significant problems were the relatively few observations and the effect of discontinuities. . . . These problems mask the overall trends in the economic development and capital structure of local firms and industries. If it can be shown, however, that there is a measurable and predictable relationship between the national and local experience, the more complete . . . national data can be used to predict the economic trends for an area.

> Differences between the level of national and local parameters and the trends in these parameters must be expected. These differences reflect the peculiar economic character of an individual area including such things as industrial mix and historical growth patterns [20:40].

WPAFB has several unique characteristics setting it apart from other areas that have been studied for flood damage. Being smaller in area and a single entity in terms of having one overall owner and mission, the Base, on the surface, may be compared to a single industrial sector. Yet there are individual organizations on the base which are unique in the diverse tasks they perform. Being federally owned the potential market value for the land and facilities at WPAFB and economic activity indexes have not been established. And, finally, WPAFB is subject to a different type of flooding than is considered in other flood studies.

Therefore, the only way that COE studies could be of value would be if damage costs could be identified for individual buildings or categories of buildings which could be compared directly with buildings or categories of buildings at WPAFB. The data source found which provided the information for the type of comparison was the flood damage surveys used in this study to investigate flood damage estimation at the second level of aggregation.

Moser and Berry, in investigating the relationships between damage values and national and local

economic indicators, attempted to predict damage costs independently of income and property market values (20:iv). To do so, they broke the industrial and commercial categories of buildings into smaller SIC classifications and obtained data from COE flood damage surveys concerning individual business establishments.

When industries were classified into SIC categories the number of establishments in each category was small. "Since these observations were based on a small sample of firms and on measurements in only three years, the overall evidence for [a factor representative of the category] was, at best, inconclusive [20:iv]."

The evaluation of the usability of the flood damage survey data consisted of a screening process. The COE Louisville District provided 386 survey forms that had been prepared for commercial and industrial establishments in the Mill Creek area north of Cincinnati, Ohio, which had experienced losses in previous floods.

The forms were first screened to i[illegible]re that they contained all necessary relevant data. If the capital value of structure and contents were not provided or if damage losses at given flood levels could not be determined from the data, the survey form was eliminated from consideration.

The screening for comparability was done by mapping the establishments surveys with the building use categories

established for WPAFB facilities in the work breakdown structure. For establishments surveyed, it could not be determined whether the tasks they performed were similar to the tasks performed in individual buildings at WPAFB. The matching of functions with the three digit facility use code categories resulted in a small number of establishments fitting any single category.

It was possible by using key words such as "warehouse," "office," and "manufacturing," to classify establishments into three broad categories according to the types of equipment, stored materials, and interior finish materials expected to be contained in the buildings as was done to originally define Air Force facilities as commercial or industrial buildings. The three categories identified were shops, warehouses, and administrative offices.

The broader categories offered the possibility of obtaining sample sizes larger than those obtained in the "Affluence Factors" study. It was realized that the resulting relationships were more general in nature and could not be applied to specific buildings or categories of buildings at WPAFB. It was also realized that because the facilities surveyed had experienced torrential flooding rather than ponding, the reported damage losses would be greater than those expected for WPAFB facilities.

The regression analysis of the data for these three general categories would provide only a general idea of the shape of a typical stage-damage curve, and the maximum damage as a percentage of replacement cost.

While these curves could not be applied to estimate damage to individual buildings, they could be used as a guide in estimating damages to specific building areas which have the characteristics of shops, warehouses, or administrative offices.

Before the regression analysis was conducted the data was further screened for the quality of data that they contained. A detailed inspection of survey forms revealed that much of the data could not be used.

The information requested by the survey form confirmed the researchers' choice of factors to be considered in flood damage estimation and the type of data required to evaluate those factors by asking for similar information. An example flood damage survey form is shown in Figures 13a and 13b. The data was obtained by contacting a representative of each firm. The information requested from that representative included the name and location of the firm, structural data concerning buildings, equipment, and material stocks, flood conditions that caused the damage, and primary damages. Structural data included the number of stories, type of construction, zero damage elevation, and the

FLOOD DAMAGE SURVEY
U. S. ARMY ENGINEER DISTRICT LOUISVILLE

Date 23 oct 68 ☐ COMMERCIAL ☒ INDUSTRIAL Appraisal C-72-C
Appraiser GE

Firm and Address

River or Stream: Mill Creek MC-4
City or Area: Lockland Ohio
Firm Name: Construction Co
Street Address: St.
Person Interviewed: Mr.

SANBORN MAP NO.
AERIAL PHOTO NO.
QUADRANGLE
OTHER Cinn Topo 4cc

STRUCTURAL DATA

Buildings	NUMBER STORIES	TYPE CONST.	BASE-MENT	ZERO DAM ELEVATION	ESTIMATED VALUE BUILDING	EQUIPMENT	STOCKS & PROD.
Main Building 2 bldgs	1 1/2	CAB	No		$15,000	$40,000	$5,000
Land 1 Acre					10,000		
TOTAL VALUE					$	$	$

FLOOD CONDITION

Flood or Identification	FLOOD	1959 FLOOD	1959+3 ft FLOOD	Design FLOOD	Design+2ft FLOOD
ELEVATION OR STAGE		545	548	552	554
DEPTH OF FLOOD ABOVE					
Basement					
First Floor			2ft	4 ft	6ft
Second Floor					

Fig. 13a. Flood Damage Survey Form (top half)

PRIMARY DAMAGES					
REAL PROPERTY					
Buildings	$	$	$	$	$
Cleaning					
Dumping					
Misc. Expenses					
TOTAL REAL PROPERTY DAMAGE			500	800	800
EQUIPMENT, STOCKS & PRODUCTS					
Machinery					
Furniture & Fixtures					
Stocks & Products					
Raw Materials					
Cleaning					
Moving					
TOTAL EQUIP., STOCKS & PROD.			1000	10,000	10,000
BUSINESS & EMPLOYMENT LOSS					
Losses Due to Business Interruption					
Employees Loss of Wages					
2 employees					
Preventive Measures					
TOTAL BUS., EMPLOY & PREV. M.					
PRIMARY DAMAGE TOTAL	$	$	$	$	$
PRIMARY DAMAGE TOTAL FOR .... UNITS	$	$	$	$	$

REMARKS

OVL FORM 122-5 Revised Feb. 1961 Engr.

Fig. 13b. Flood Damage Survey Form (bottom half)

estimated value of buildings, equipment, and stocks. The flood conditions were stated in depth in feet above the basement, first, or second floor (usually above the first floor). The primary damages were identified by type of damage to real property, to equipment and stocks, and indirect damages of business interruption, loss of wages, and required preventive measures.

The form provides an excellent guide to the types of damage factors to be looked at, but there are some weaknesses in using the form. The COE flood damage surveys are conducted to support their studies on a national or regional scale; the estimate for an individual building does not have to be extremely accurate since it is aggregated with a large number and variety of buildings. The primary disadvantage in the form itself is that the data is not contained in a form that can be analyzed using automated data processing techniques. The second weakness is that there are no standardized procedures of data collection and methods of data use. Without this standardization there is no guarantee that data entries on the form have the same meaning to the user as had been intended by the collector. This aspect becomes even more important when automated data processing is considered, because a computer does not have the flexibility of interpreting the intended meaning of widely varying data symbols.

This lack of standardized procedures necessitated considerable interpretation by the researchers. There was a wide variety of descriptions of type of construction which could have been classified simply as masonry. At the same time, some entries for construction type stated masonry and frame with no indication of the relative proportions of each structural type. In another example, there were two forms that contained remarks stating that the establishments had attached service pits. One establishment counted the pits as a basement, while the other did not.

Other problems in data gathering procedures included obvious incongruencies in the data and aggregated values for capital stocks and damages. A typical incongruency was the difference between two flood stages reported as three feet while the height above the first floor showed a difference of only two feet. Since floor elevation and zero damage elevation were not filled in on the form, there was no way to determine which was the correct figure.

A typical problem with the aggregated values of capital was that a "lump sum" value was given for two or more buildings, or structural value was separated by buildings while equipment and stock values were aggregated for the entire establishment.

Since real property records for AF facilities include the cost of installed equipment but exclude the cost of user supplied equipment, it was not possible to express the three types of value data in terms of replacement cost as is done for Air Force facilities. Many of the forms provided only a "lump sum" estimate of damage for given flood levels. The sum of the damage for some establishments was recorded as occurring only to the building, while other establishments included equipment, stocks, and products. Damage estimates were usually provided as round figures, some to the nearest $100,000.

In order to obtain data for the regression analysis, it was necessary to select surveys for establishments in which the damage estimates at given elevations appeared to define a stage-damage curve for that establishment.

The screening process eliminated a large number of establishments from consideration. Surveys which appeared to provide useful stage-damage curve data were identified for thirty buildings which were classified as repair shops (automobile body shops, refrigeration shops, plumbing shops, etc.), twenty-six buildings which were classified as administrative offices (insurance agencies, banks, real estate offices, etc), and twenty-six warehouses.

The results of the regression analyses were inconclusive, with correlation coefficients of .045 for shops,

.203 for offices, and .49 for warehouses. The square of the correlation coefficients for each of the three categories was less than 0.5. The meaning of this statistic was that less than half of the total variation in damage was explained by the regression of that variable with water level (21:423). The findings were that the flood damage surveys obtained from the COE Louisville District could not be used to determine the shape of the stage-damage curves for WPAFB facilities. The shape of stage-damage curves would have to be obtained through the analysis of individual buildings using the various construction estimating techniques as was done in the preliminary estimates which were obtained by the interview technique for all the flood damage studies reviewed. The individual analyses could be conducted by using the computer programs described in Chapter III.

Expected Value of Flood Damage

The application of the computer programs resulted in the following expected values of damages.

The program, COST, run for the 500-year flood plain under the initial assumptions of a straight line damage to water level function identified the seventy-seven buildings in the flood plain and computed an expected average annual value of damages to those facilities of $67,832. The average annual cost of damages to the following ten key buildings contributed 47 percent of the total expected annual cost.

TABLE 5

KEY BUILDINGS DAMAGED BY FLOODING

Bldg	Expected Annual Cost	Percent of Total Expected Annual Cost (cummulative)
206	$ 6,816	10%
67	6,384	19
4066	2,775	23
93	2,732	28
148	2,526	31
851	2,317	35
268	2,152	38
4042	2,054	41
142	2,047	44
90	1,964	47
Total Expected Annaul Cost	$67,832	100%

Of these ten buildings only four are included in the 100-year flood plain for which planning is required by EO 11988.

Running the program for the 100-year flood plain identified twenty-seven buildings in the flood plain and computed an expected average annual value of damages to those facilities of $24,928. Because the probabilities of the respective flood elevations being exceeded is greater for facilities in the 100-year flood plain, the expected cost was a higher percentage of the replacement cost, even though it was still less than 1 percent. Much of the increase in expected cost for facilities in the 500-year flood plain was due to the high replacement cost of some

facilities even though the probability of their floor elevations being exceeded was lower than for facilities in the 100-year flood plain.

The program, ANCOST, traced the average annual expected cost through each one foot interval of flooding from 800 feet MSL to 820 feet MSL. The upper elevation boundary of the program included the seventy-seven buildings in the 500-year flood plain elevation of 819.1 feet MSL. The cumulative average annual cost of flooding up to the upper boundary elevation increased with each one foot increase in elevation up to a value of $29,942. A graph of the expected cost of damage at each elevation is shown in Figure 14. The cumulative expected cost of flooding up to each elevation is determined by the area under the curve defined for that range of elevations. The remainder of the $67,832 expected cost for flooding of facilities in the 500-year flood plain which was computed by the program, COST, was due to the additional area under the expected cost curve associated with floods exceeding 820 feet MSL.

The average annual cost of flooding up to 811 feet MSL which included twenty-six of the twenty-seven buildings in the 100-year flood plain was $3,866. A graph of the cumulative average annual expected cost of flooding up to a given elevation is shown in Figure 15.

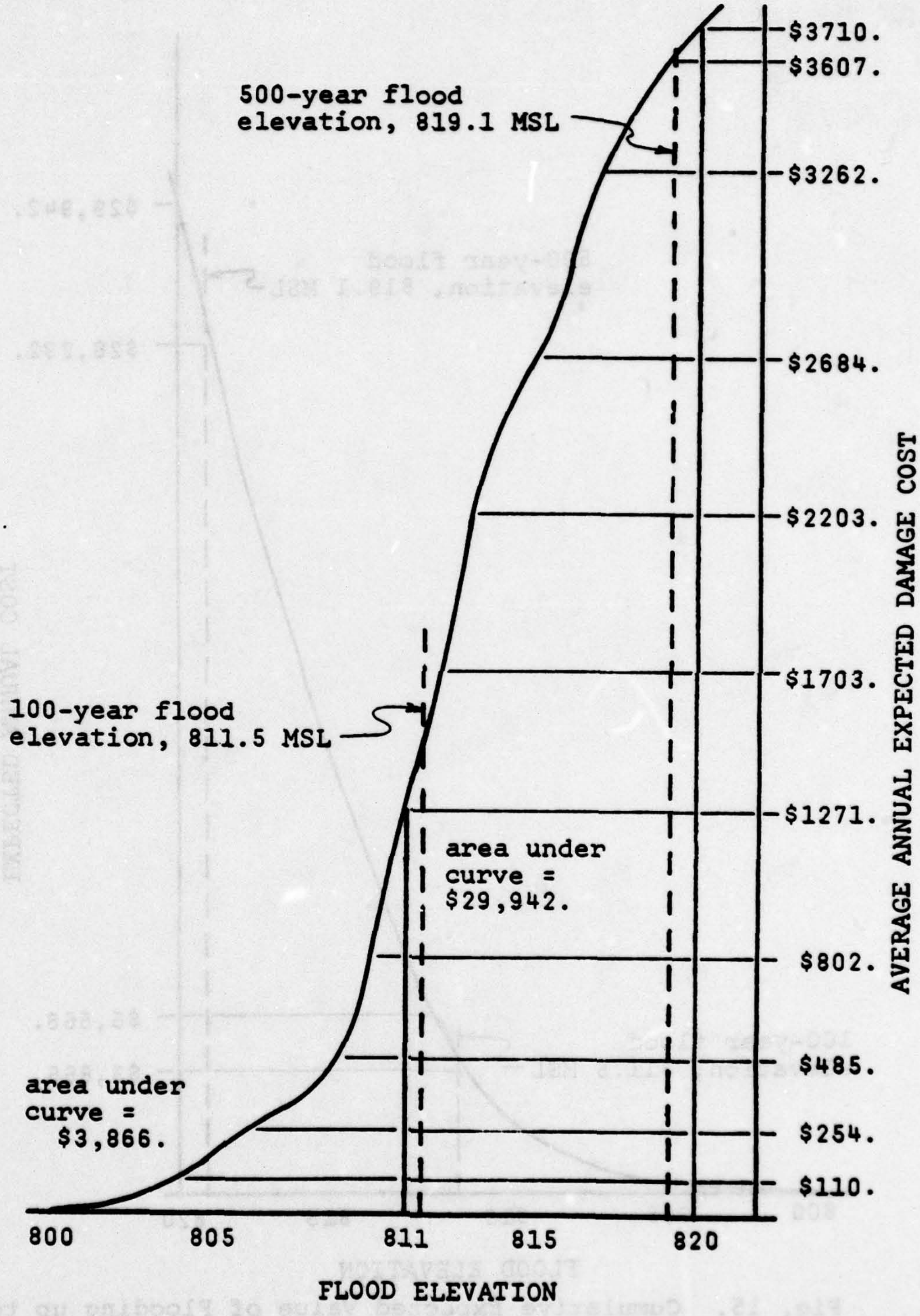


Fig. 14. Average Annual Expected Cost of Flooding as a Function of Flood Elevation

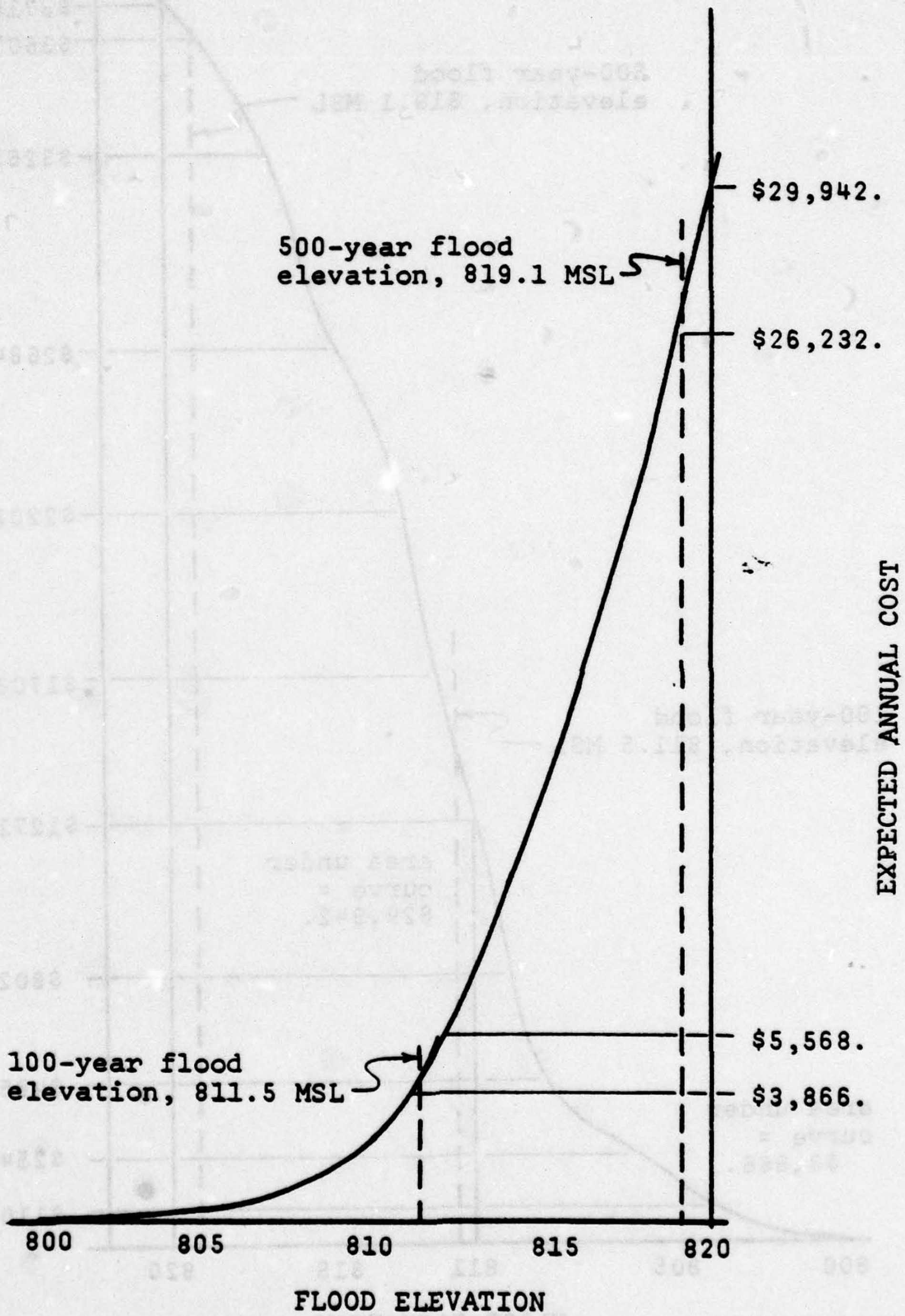


Fig. 15. Cumulative Expected Value of Flooding up to a Given Elevation

A correlation analysis of the cumulative expected cost with respect to flood recurrence interval using SPSS subprogram SCATTERGRAM (21:293) computed the slope of a regression line of .06 and a correlation coefficient of .99. The analysis showed that the expected average annual cost of flood damage up to an elevation with a given expected recurrence interval is a function of that recurrence interval defined by the equation:

$$E = \$60 \times R$$

where: E = expected cost

R = recurrence interval.

Changing the maximum expected damage parameter by multiplying the facility replacement cost by a factor resulted in each expected value of damage computed by the program being multiplied by the same factor. Changing the stage-damage curve to simulate 20 percent of the maximum damage to a facility occurring as the water level increased to one-half of the eave height and the remaining 80 percent of the damage occurring as the water level increased to the eave height resulted in a 42 percent reduction in average annual expected costs for the 100-year flood. Reversing the factors, so that 80 percent of the maximum damage occurred as the water level increased to one-half of the eave height, resulted in an increase of 42 percent in average annual expected costs.

The results demonstrated the sensitivity of the expected cost analysis to assumptions concerning the two parameters. The 42 percent change is a difference of \$10,420.

A 42 percent increase in the expected annual average cost of damage to facilities in the 100-year flood raises the figure from \$24,928 to \$35,348. Combining that parameter change with a maximum damage cost factor of 1.5 times the facility replacement cost results in an expected cost of \$53,022.

Assuming that the lower stage-damage curve applies and using a maximum damage cost factor of .5 times facility replacement costs results in a low figure of \$7,254 expected average annual value. In a similar analysis for facilities in the 500-year flood plain the expected cost ranged from \$17,219 to \$151,840. The range of values is especially wide for the larger flood plain where the probability of flooding becomes a smaller factor and the number of buildings and the high replacement cost of some of them becomes a major factor.

The changing of factors in the programs demonstrated the operation of the programs and the effects of varying the assumptions concerning the parameters in the damage estimation process, but it did not reveal which assumption would be more valid. As stated earlier in this chapter, further

refinement of the assumed parameters requires an analysis of individual buildings.

The analysis of flood damage surveys did not provide conclusive guidance in the determination of the shape of stage-damage curves for the cost model for specific buildings, categories of buildings, or categori s of types of activity areas. But the classification of facilities to categories in the work breakdown structure did allow some general observations of data patterns to be made.

The categorization by structural type only identified a few structures as exceptions. There were only three wood buildings. The wood structures were a small building at the small arms range, a small golf course equipment shed, and a 16,800 square foot base engineer maintenance facility. The small arms range was identified as an exceptional structure because it consisted only of earth berms, concrete slabs, and heavy wooden range baffles.

The remainder of the buildings were masonry and metal structures on concrete foundations. Both masonry and metal buildings ranged from low to high cost and from small to large size according to square footage. There were no other structural characteristics to further classify buildings other than those connected with a particular use of the facility.

Under the initial classification of facilities, according to the criteria described in Chapter III, into industrial and commercial facilities, almost all buildings were in the industrial category. Those that were not industrial were operations and training facilities with use codes 14X or 17X, administrative facilities with use code 610, or recreation facilities with use codes of 740 or 750.

While the categorization into industrial and commercial did identify manufacturing type processes versus sales and customer service activities, it did not identify characteristics describing susceptibility to damage as was originally expected.

By looking at the facility use codes, groups of buildings with similar characteristics could be identified. There were eleven facilities with a use code in the 100 series (see appendix B). Each of those facilities is a unique building requiring individual analysis.

There were eleven maintenance hangars identified by a facility use code 211. All eleven buildings in this category were among the nineteen buildings with the highest replacement cost of all buildings in the 500-year flood plain, but none of the buildings were in the 100-year flood plain. Primarily because of the high replacement cost, three of the buildings were among the ten buildings with the

highest expected average annual damage cost. With the exception of building 105 all were open bay metal structures. A stage-damage curve developed for one of the maintenance hangars could possibly be applied for each of the hangars except for building 206.

Building 206, because of its exceptionally high replacement cost and large size, contributed 10 percent of the expected average annual cost of damage to all facilities in the 500-year flood plain, even though the probability of its floor elevation being exceeded is only .005. The building is a three story structure which would require individual analysis with emphasis on damage to equipment and materials on the first floor to obtain a stage-damage curve.

The remaining fifteen buildings with use codes in the 200 series could be characterized as maintenance shops but contain widely varying amounts of office and storage space. Individual analysis would be required to determine whether a single stage-damage curve could be applicable to buildings in those categories.

There were only two research facilities, buildings 67 and 4014, with use codes 310 within the 500-year flood plain. But they were among the nineteen facilities with replacement cost of over one million dollars, and building 67 was the second largest contributor to the expected

average annual damage cost to all facilities in the 500-year flood plain. A separate stage-damage curve would be required for these facilities.

The facility use codes in the 400 series identified warehouse facilities. With the exception of building 28, which is housing supply, all the warehouses in the 500-year flood plain were for hazardous material storage or munitions storage. The hazardous material storage buildings were small outlying buildings. Little damage would be expected to occur to the structures, but there could be possible significant damage to the contents. While the shape of the stage-damage curves for these facilities may be similar, the maximum expected damage value would have to be set by the responsible user of the contents.

The munitions storage facilities were predominately larger and more expensive to replace than the hazardous material storage facilities, but otherwise would require a similar analysis of damage to contents. Six storage buildings in the munitions storage area were in the 100-year flood plain.

The four administrative facilities with facility use code of 610 had floor elevations between 818 and 819 feet MSL, placing them among the last buildings in the 500-year flood plain to be flooded. Three of the four buildings are among the nineteen buildings with replacement cost of

over one million dollars. Much of their high replacement cost is attributable to the types of materials and contents used in the offices they contain. Those same characteristics would describe the type of damage expected to occur.

There are four facilities with facility use codes of 740 or 750 which accounts for most of the damage to recreation facilities. The two Rod and Gun Club buildings have a low replacement cost compared to other buildings in the 500-year flood plain, but have a relatively significant expected average annual damage cost because they are second only to the small arms range in the probability of flooding. The remaining two facilities are the golf club house and the tennis club which would require individual analysis. The golf course grounds are a separate area of flood damage which was not included in this study.

Facility use codes in the 800 series identified buildings associated directly with utility distribution systems. Two electric power stations and two utility vaults were identified. These four buildings and outlying transformer stations would be analyzed to determine damage to the electrical distribution system.

Four water pump stations and one water supply building were also identified. One of the four pump stations, building 851, is among the ten buildings with highest expected average annual cost; however, because water pump

stations are designed to be protected from water damage the assumption in the program of maximum damage equal to replacement cost greatly over estimated the damage to those facilities. A primary concern with the water and sewer system is the possibility that the drinking water may become contaminated. That consideration deals with indirect damages and was not included in this study. While the well points supplying water to Area "B" of WPAFB are in the 100-year flood plain, the effects of flooding on those facilities would be a separate study conducted by base personnel.

The observations made for the various use categories showed that the classification of buildings by use did not necessarily provide the information required to determine the shape of stage-damage curves. There were some groups of buildings that shared common characteristics that would indicate that their stage-damage curves would be similar.

The findings of the classification process showed that the categorization by any single classification principle was not adequate to define the parameters of the cost model. The determination of maximum damage as a percentage of replacement cost and the shape of the stage-damage curve for each building depended upon a combination of factors. Those factors, including use, type of construction, equipment and material contents, and special considerations such as number of floors, can only be analyzed

through the individual investigation of damage to each building. The categorization by use was the most useful method of defining the work breakdown structure to identify which of those factors would be important for determining the cost model parameters for individual buildings or small groups of buildings.

The investigation of each building requires the estimator to visualize the damage that would be caused by flood waters in a building and to reduce his observation to a quantification of cost to repair the damage using standard construction estimating techniques. The cost model simplifies that task by identifying key buildings to look at, and by reducing the quantification of cost to the determination of four cost model parameters. The trade-off between the level of accuracy required and the resources to be allocated to performing the estimate determine how closely the parameters must be approximated.

CHAPTER V

CONCLUSION

This study addressed a question that has been a matter of concern for WPAFB for many years, although the degree of attention that should be given to answering that question was not known. In order to answer the question there was a need to study the likelihood of flooding and the extent of potential damage that might occur.

The objectives of this study were threefold:

1. To examine the basis of flood predictions for the Huffman Dam flood plain and establish flood elevation probabilities.

2. To explore methods of predicting the degree of damage to structures, real property installed equipment, building contents, and other real property as a function of flood elevation.

3. To develop a measurement tool to quantify the monetary loss expected for flooding at various elevations, which can then be used to evaluate alternatives to reduce potential flood damage.

Three methods of flood probability analysis common in the field of hydrological engineering were identified and evaluated. The statistical analysis of the recurrence

interval of observed floods occurring between 1922 and 1977 provided the strongest predictor of flooding at WPAFB. Based on that analysis the likelihood of flooding was predicted and stated both in terms of the elevations associated with the given recurrence intervals and in terms of the probability of a given flood elevation being exceeded in any given year. A summary of the predictions was presented in Table 4. The 100-year flood was identified as 811.5 feet MSL and the 500-year flood as 819.1 feet MSL.

Estimating principles and techniques were explored to determine how they could be applied to predict the extent of flood damages. The flood damage studies performed for other flood plains of the United States were reviewed to examine the approaches they took to flood damage estimation and determine whether similar approaches could be applied to the WPAFB flood plain.

Three typical studies used for developing flood control programs were those performed for the Ohio River System (28), the Upper Colorado River System (26), and the Alabama-Coosa River System (22). The findings of that review were that those studies were conducted on a larger scale and for much larger regions than was required for WPAFB. Estimates of direct damage to facilities used in those studies were obtained from separate supporting analyses which were not described in detail in the major study;

therefore, the studies contained little information that could be used at WPAFB.

A typical supporting analysis was the Potential Flood Damage Study for Dry Creek, Goodlettsville, Tennessee (2). That study demonstrated the use of the stage-damage curve to describe the extent of damage associated with varying water levels in a building. The "Goodlettsville" study also demonstrated the assessing of the damage to utility distribution systems as it occurred to individual structural components of the system.

Although the "Goodlettsville" study used the stage-damage curve to describe flooding to residential facilities and a composite stage-damage curve to describe damage to all buildings in the study area, it did not present the stage-damage curve for commercial, industrial, and public buildings. Because of the varying nature of those buildings, the damage to specific commercial, industrial, and public facilities were obtained for that study through interviews and separate damage analyses for individual buildings.

The Emperical Investigation of the Existence and Magnitude of a Commercial and Industrial Affluence Factor (20) attempted to establish relationships between damage to structures and contents and the capital values of commercial and industrial establishments by correlation analysis, but the results were inconclusive because of the restricted

sample size and limited usability of the flood damage survey data. The study of WPAFB facilities performed a similar analysis of flood survey data and attempted to overcome the problems encountered in the "Affluence Factor" study by establishing more general categories to enlarge the sample size.

Three categories were established based on the equipment and material content, and the expected susceptibility to flood damage of certain types of building areas. The types of areas identified were shops, warehouses, and offices. The problems of usability of data were such that conclusive results could not be achieved with the data obtained from the Louisville District of the COE. In order to define stage-damage relationships using COE flood damage surveys, it would be necessary to resurvey many establishments to obtain data at a more detailed level than was required in the original surveys.

The results of this study were that no method was found that could predict flood damage costs by comparing the WPAFB situation to other areas which have experienced flooding in the past or have been the subject of flood damage studies. The estimation of damage requires the individual evaluation of damage to each involved facility, using construction estimating techniques.

Using the estimating principles described in AFSCM 173-1 (6) a cost model was developed which provided a rough

estimate of expected damage costs and which can guide the analysis of costs by investigation of individual buildings.

The study identified the facilities in the 500-year flood plain. Data was collected for each facility, including floor elevation, height of structure, and replacement cost. The cost model was developed using those three data elements and a set of assumptions relating damage costs to those parameters. Two computer programs were developed using the cost model to obtain the expected average annual value of potential flooding at WPAFB. The first program, COST, provided the expected annual value of flood damage to each building in a given flood plain up to the 500-year flood, and was used to identify ten key buildings which contributed the greatest amount to the total expected annual cost of flooding in the 500-year flood plain.

The second program, ANCOST, provided a composite stage-damage curve for flooding at WPAFB up to the 500-year flood elevation.

Data was also collected on the type of construction, number of floors, gross area and use of each building. Buildings were classified first by type of construction, then by facility use in order to investigate the use of those data elements to determine stage-damage curves and to refine the assumptions concerning the parameters used in the cost model. Although the classification process did not

identify categories of buildings and define the cost model assumptions to apply to those categories, the classifications did allow the observations of data patterns which can be used to guide the analysis of damage to specific buildings and small groups of buildings.

To obtain a more accurate estimate of the expected average annual value of flood damage to WPAFB facilities, it is recommended that the computer programs be further revised to obtain the elevation at which damage begins to occur, the elevation at which maximum damage occurs, the replacement cost of the facility, and a coded shape of the stage-damage curve for the facility, from the data file for each building. The shape of the stage-damage curve would be a separate data element determined by a combination of factors, including the four data elements considered earlier in the classification process.

The process described in this study provides an estimate of the expected average annual value of direct damages to facilities caused by flooding.

The consideration of the total impact of flooding on WPAFB must include the determination of indirect costs and the weighing of the interruption of base activities. The estimates provided by the analyses described in this study are factors to be considered in the economic analysis of proposed actions to protect facilities from flooding or actions which might increase the flood hazard at Wright-Patterson Air Force Base.

APPENDIXES

APPENDIX A

HUFFMAN RETARDING BASIN OPERATION
1922-1977

HUFFMAN RETARDING BASIN OPERATION

1922 - 1977

NO.	DATE	MAX ELEV.	DEPTH	STORAGE AC. FT.	POOL AREA ACRES	MAXIMUM OUTFLOW C.F.S.
SPILLWAY POOL		835.0	58.0	167000	9180	35000
1	JAN 22, 1959	809.0	32.0	25000.	2750.	21200.
2	FEB 26, 1929	805.2	28.2	14100.	2010.	18400.
3	MAR 5, 1963	804.1	27.1	12500.	1700.	18500.
4	JAN 21, 1937	801.0	24.0	7800.	1260.	15400.
5	JAN 27, 1952	800.8	23.8	7550.	1225.	13300.
6	JAN 15, 1937	799.8	22.8	6600.	1060.	13400.
7	FEB 14, 1948	799.3	22.3	6100.	1000.	13300.
8	MAR 29, 1924	798.0	21.0	4800.	840.	12500.
9	MAR 10, 1964	797.7	20.7	4500.	850.	12800.
10	FEB 11, 1959	797.2	20.2	4200.	760.	11600.
11	JUN 3, 1947	797.0	20.0	4050.	740.	12000.
12	JUN 9, 1924	796.8	19.8	3900.	720.	10600.
13	MAY 14, 1933	796.7	19.7	3800.	700.	10500.
14	MAR 7, 1945	796.5	19.5	3650.	680.	11400.
15	JUN 14, 1958	796.5	19.5	3650.	680.	10400.
16	MAR 20, 1943	796.1	19.1	3300.	650.	11200.
17	FEB 24, 1975	796.0	19.0	3100.	630.	11000.
18	APR 5, 1957	795.7	18.7	3000.	630.	9900.
19	APR 15, 1922	794.7	17.7	2500.	550.	9200.
20	DEC 31, 1932	794.5	17.5	2350.	530.	9100.
21	FEB 22, 1951	794.5	17.5	2350.	530.	9100.
22	JAN 6, 1949	794.4	17.4	2310.	520.	9000.
23	DEC 4, 1950	794.4	17.4	2310.	520.	9000.
24	JAN 20, 1927	793.9	16.9	2100.	490.	8700.
25	JAN 17, 1950	793.8	16.8	2060.	480.	8600.
26	APR 3, 1970	793.6	16.6	1950.	460.	9170.
27	MAR 21, 1927	793.2	16.2	1800.	440.	8200.
28	JAN 19, 1929	792.9	15.9	1650.	420.	8000.
29	FEB 15, 1950	792.8	15.8	1630.	415.	7900.
30	MAY 28, 1968	792.7	15.7	1600.	410.	8800.
31	JUN 11, 1958	792.7	15.7	1600.	410.	7800.
32	JAN 10, 1930	792.5	15.5	1500.	400.	7600.
33	MAR 19, 1933	792.1	15.1	1400.	370.	7400.
34	JAN 7, 1950	792.1	15.1	1400.	370.	7400.
35	JAN 11, 1950	791.9	14.9	1370.	365.	7300.
36	MAY 15, 1929	791.8	14.8	1350.	360.	7200.
37	APR 7, 1938	791.6	14.6	1100.	340.	7000.
38	APR 12, 1944	791.6	14.6	1100.	340.	7000.
39	FEB 16, 1949	791.5	14.5	1100.	340.	6820.

40	JAN 4, 1951	791.5	14.5	1100.	340.	6820.
41	JUN 26, 1971	791.4	14.4	1100.	330.	7600.
42	JUL 4, 1975	791.3	14.3	1075.	320.	7300.
43	FEB 27, 1962	791.2	14.2	1050.	315.	7140.
44	MAY 24, 1968	791.1	14.1	1030.	310.	7400.
45	APR 22, 1964	791.0	14.0	1020.	300.	6800.
46	JAN 18, 1932	790.8	13.8	1000.	290.	6500.
47	APR 15, 1939	790.7	13.7	950.	280.	6400.
48	APR 21, 1964	790.6	13.6	930.	275.	6300.
49	AUG 10, 1969	790.4	13.4	900.	270.	6800.
50	FEB 13, 1951	790.4	13.4	900.	270.	6430.
51	JAN 28, 1949	790.4	13.4	900.	270.	6430.
52	JAN 22, 1927	790.4	13.4	900.	270.	6200.
53	APR 25, 1937	790.4	13.4	900.	270.	6200.
54	JAN 28, 1949	790.4	13.4	900.	270.	6200.
55	JAN 30, 1969	790.2	13.2	850.	260.	6700.
56	MAR 12, 1952	790.2	13.2	850.	260.	6240.
57	JAN 25, 1929	790.2	13.2	850.	260.	6100.
58	APR 26, 1961	790.2	13.2	850.	260.	6980.
59	MAR 21, 1945	790.0	13.0	830.	260.	6070.
60	NOV 17, 1955	790.1	13.1	840.	260.	6050.
61	MAR 24, 1948	790.0	13.0	830.	260.	6050.
62	APR 14, 1948	790.0	13.0	830.	260.	6050.
63	APR 5, 1950	790.0	13.0	830.	260.	6050.
64	DEC 1, 1927	789.9	12.9	800.	240.	6420.
65	APR 25, 1970	789.8	12.8	800.	240.	6260.
66	FEB 27, 1936	789.8	12.8	800.	240.	5900.
67	APR 21, 1940	789.8	12.8	800.	240.	5900.
68	JAN 25, 1950	789.8	12.8	800.	240.	5870.
69	JAN 15, 1951	789.6	12.6	660.	240.	5690.
70	MAR 23, 1952	789.6	12.6	660.	240.	5690.
71	FEB 23, 1971	789.5	12.5	640.	230.	6200.
72	MAY 5, 1958	789.4	12.4	620.	225.	5580.
73	JUN 20, 1973	789.4	12.4	620.	225.	4000.
74	JAN 31, 1947	789.4	12.4	620.	225.	5510.
75	JAN 30, 1970	789.3	12.3	600.	220.	5920.
76	FEB 27, 1930	789.3	12.3	600.	220.	5500.
77	MAR 16, 1938	789.3	12.3	600.	220.	5500.
78	DEC 15, 1977	789.3	12.3	600.	220.	5900.
79	APR 19, 1933	789.0	12.0	550.	200.	5400.
80	JAN 18, 1969	788.6	11.6	500.	185.	5600.
81	APR 3, 1977	788.6	11.6	500.	185.	5350.
82	MAY 22, 1957	788.4	11.4	470.	175.	5050.
83	AUG 3, 1958	788.4	11.4	470.	175.	5050.
84	MAR 17, 1943	788.3	11.3	450.	170.	5000.
85	NOV 14, 1972	788.2	11.2	500.	150.	5250.
86	JUN 25, 1969	788.2	11.2	500.	150.	5300.
87	APR 26, 1965	788.2	11.2	500.	150.	5160.
88	FEB 5, 1971	788.1	11.1	400.	165.	5250.
89	APR 2, 1974	788.1	11.1	400.	165.	5000.
90	MAR 5, 1964	788.1	11.1	400.	165.	4900.
91	JAN 31, 1939	788.0	11.0	400.	160.	4800.

APPENDIX B

DATA FILE FOR WRIGHT-PATTERSON AIR FORCE BASE FACILITIES IN THE 500-YEAR FLOOD PLAIN

FACILITIES IN THE 100-YEAR FLOOD PLAIN

BLDG. NO.	FLOOR ELEV. (FT.MSL)	GROSS AREA (SQ.FT)	TYPE CONST	EAVE HEIGHT (FT)	REPL. VALUE ($1000)	USE CODE
886	800.5	2000	4	15.0	24.	179
890	801.2	300	2	10.0	3.	171
889	802.7	270	3	10.0	3.	171
891	802.9	1200	2	10.0	21.	740
892	803.5	1222	1	10.0	58.	740
962	805.0	186	1	10.0	97.	134
894	805.8	2256	2	20.0	33.	219
4066	807.8	2080	1	10.0	307.	216
851	808.9	340	1	2.0	165.	842
814	809.2	100	1	10.0	1.	750
4053	809.5	1619	1	8.0	240.	730
887	809.5	240	1	10.0	77.	211
882	809.5	300	2	10.0	91.	134
4054	810.0	1152	2	10.0	97.	442
813	810.0	6584	1	16.0	325.	750
4065	810.2	249	4	10.0	91.	422
4058	810.2	1560	4	10.0	181.	422
4040	810.2	299	1	10.0	46.	841
852	810.4	312	1	2.0	60.	842
4067	810.5	8280	1	20.0	507.	216
93	810.5	12501	1	14.0	694.	171
4083	810.7	1560	4	10.0	132.	422
4082	810.7	1560	4	10.0	132.	422
4081	810.7	1560	4	10.0	132.	422
61	810.9	575	1	10.0	30.	750
50	810.9	87	1	10.0	5.	890
90	811.3	26694	2	14.0	591.	740

ADDITIONAL FACILITIES IN THE 500-YEAR FLOOD PLAIN

BLDG. NO.	FLOOR ELEV. (FT.MSL)	GROSS AREA (SQ.FT)	TYPE CONST	EAVE HEIGHT (FT)	REPL. VALUE ($1000)	USE CODE
4052	811.5	1262	1	10.0	261.	730
39	811.5	202	3	8.0	5.	750
4060	811.7	600	1	10.0	25.	422
4041	811.7	2612	1	24.0	20.	149
67	811.7	40227	1	14.0	2090.	310

FACILITIES IN THE 500-YEAR FLOOD PLAIN (CONT.)

BLDG. NO.	FLOOR ELEV. (FT.MSL)	GROSS AREA (SQ.FT)	TYPE CONST	EAVE HEIGHT (FT)	REPL. VALUE ($1000)	USE CODE
148	812.0	32608	2	30.0	1793.	211
4064	812.6	7074	1	10.0	359.	422
4062	812.6	7074	1	10.0	353.	422
268	813.5	41138	2	29.0	2028.	211
181	813.8	266	1	9.0	125.	842
4029	814.2	439	1	10.0	65.	811
104	814.7	4233	2	10.0	18.	218
273	814.9	412	1	10.0	120.	842
206	815.0	171548	2	49.0	14866.	211
106	815.0	2400	1	14.0	215.	218
4046	815.4	4685	1	13.0	353.	218
118	815.4	283	1	10.0	7.	890
105	815.5	9280	1	17.0	1033.	211
4047	816.0	152	2	10.0	15.	442
4042	816.0	32300	2	19.0	2186.	217
4004	816.0	17693	1	13.0	1219.	141
145	816.1	35536	2	20.0	2062.	211
141	816.1	526	1	10.0	325.	811
99	816.1	746	1	10.0	26.	442
4033	816.2	600	1	11.0	51.	121
4031	816.4	320	1	10.0	12.	219
4030	816.5	1462	1	10.0	43.	125
4044	817.0	1408	1	13.0	203.	214
4032	817.0	1504	1	12.0	66.	121
4027	817.3	400	2	20.0	16.	442
4028	817.4	28000	2	29.0	1108.	211
4026	817.4	28000	2	29.0	1114.	211
4024	817.4	41794	2	29.0	2009.	211
4022	817.4	28000	2	29.0	1090.	211
4020	817.4	16000	2	28.0	1168.	211
109	817.5	20283	1	24.0	684.	218
152	817.8	35371	2	25.0	1728.	211
100	817.9	66	1	10.0	3.	422
4008	818.0	1000	1	13.0	77.	610
142	818.1	26247	1	14.0	2590.	214
110	818.1	30720	1	15.0	1958.	610
29	818.4	16800	3	10.0	845.	219
28	818.5	4696	1	10.0	116.	442
4014	818.6	43748	1	20.0	1848.	310
20	818.8	3480	1	10.0	116.	219
57	818.9	708	1	16.0	66.	890
4048	819.0	4040	2	14.0	161.	229
4012	819.0	53141	1	20.0	3148.	610
4010	819.0	22667	1	20.0	1240.	610
27	819.0	11520	2	10.0	84.	219

APPENDIX C

FORTRAN PROGRAM "COST"

```
CALL ATTACH(11,"UPDATA.R;",1,0,,)
WRITE(5,701)
701FORMAT(/////,20X,"COST")
WRITE(5,700)
WRITE(5,499)
499FORMAT("   THIS PROGRAM COMPUTES AN AVERAGE ANNUAL EXPECTED VALUE")
WRITE(5,500)
500FORMAT("OF FLOOD DAMAGE FOR A SELECTED FLOOD PLAIN.  ENTER THE")
WRITE(5,501)
501FORMAT("RECURRENCE INTERVAL OF THE FLOOD YOU WISH TO PLAN FOR.")
READ(6,99) YEAR
NYEAR=YEAR
99FORMAT(V)
UPROB=1/YEAR
PERCENT=UPROB*100
EL=789.652+(10.9009*ALOG10(YEAR))
WRITE(5,699)
699FORMAT(//)
WRITE(5,199)
199FORMAT("   THE FLOOD SELECTED TO DESCRIBE THE FLOOD PLAIN IS THE")
WRITE(5,200) NYEAR
200FORMAT(1H ,I3,"-YEAR FLOOD.  THAT FLOOD ELEVATION WOULD BE EXCEEDED")
WRITE(5,201)
201FORMAT("IN THE LONG RUN WITH A RELATIVE FREQUENCY OF ONCE IN")
WRITE(5,202) NYEAR
202FORMAT(1H ,I3," YEARS.  ANOTHER WAY OF STATING THE RISK IS THAT THE")
WRITE(5,203)
203FORMAT("PROBABILITY OF THAT ELEVATION BEING EXCEEDED IN ANY GIVEN")
WRITE(5,204) UPROB,PERCENT
204FORMAT("YEAR IS ",F5.3,", OR ",F3.1," PERCENT.")
WRITE(5,205) EL
205FORMAT("THE ELEVATION OF THE SELECTED FLOOD IS ",F5.1," FEET MSL.")
WRITE(5,699)
WRITE(5,299)
299FORMAT("   THE FOLLOWING BUILDINGS ARE INCLUDED IN THE SELECTED")
WRITE(5,300)
300FORMAT("FLOODPLAIN:  ALSO PROVIDED IS THE FLOOR ELEVATION, THE")
WRITE(5,301)
301FORMAT("PROBABILITY OF THE FLOOR ELEVATION BEING EXCEEDED, THE")
WRITE(5,302)
302FORMAT("REPLACEMENT COST, AND THE AVERAGE ANNUAL EXPECTED VALUE")
WRITE(5,303)
303FORMAT("OF DAMAGES FOR EACH BUILDING.")
WRITE(5,240)
240FORMAT("WHAT FACTOR TIMES THE REPLACEMENT COST IS THE MAXIMUM")
WRITE(5,241)
241FORMAT("EXPECTED DAMAGE TO THE BUILDINGS?")
READ(6,99) FACTOR,FACTA,FACTB
700FORMAT(////)
```

```
1377 WRITE(5,700)
1380 WRITE(5,304)
1390 304FORMAT("BUILDING      FLOOR    PROBABILITY  REPLACEMENT  ANNUAL")
1400 WRITE(5,305)
1410 305FORMAT("  NUMBER    ELEVATION  OF FLOODING  COST ($1000)  COST")
1420 N=0
1430 TCOST=0
1440 SUMCOST=0
1450 DO 13 I=1,77
1460 READ(11,100) LN,NBLDG,ELEV,NSQFT,NCONST,EAVENT,REPCOST,NUSE
1470 100FORMAT(I4,1X,I4,1X,F5.1,1X,I6,I2,1X,F4.1,1X,F6.0,1X,I3)
1480 IF(ELEV.GT.EL) GO TO 13
1490 TPROB=1/(10**((ELEV-789.652)/10.9009))
1500 BCOST=0
1510 LN=EAVENT+1
1520 DO 15 J=1,LN
1530 PROBINT=1/(10**((ELEV+J-1-789.652)/10.9009))
1540 PROBNXT=1/(10**((ELEV+J-789.652)/10.9009))
1550 PROB=PROBINT-PROBNXT
1555 F=J
1556 RC=REPCOST*FACTOR
1560 DAMAGE=RC*((F-0.5)/EAVENT)
1561 HTAFLR=J-ELEV
1562 IF(HTAFLR.LT.(EAVENT/2)) DAMAGE=((F-0.5)/(EAVENT/2))*RC*FACTA
1563 ELEVEL=(EAVENT-F+0.5)/(EAVENT/2)
1564  IF(HTAFLR.GE.(EAVENT/2)) DAMAGE=RC-(ELEVEL*RC*FACTB)
1570 ESTCOST=DAMAGE*PROB
1580 PROBFIN=1/(10**((ELEV+EAVENT-789.652)/10.9009))
1590 IF(J.GT.EAVENT) ESTCOST=RC*PROBFIN
1600 BCOST=BCOST+ESTCOST
1605 BACOST=BCOST*1000
1620 15 CONTINUE
1630 WRITE(5,306) NBLDG,ELEV,TPROB,REPCOST,BACOST
1640 306FORMAT(2X,I4,7X,F5.1,7X,F5.3,7X,F6.0,4X,F7.2)
1650 N=N+1
1660 TCOST=TCOST+REPCOST
1670 SUMCOST=SUMCOST+BCOST
1680 13 CONTINUE
1685 WRITE(5,699)
1690 WRITE(5,399) N
1700 399FORMAT("   IN SUMMARY, ",I2," BUILDINGS ARE IN THE FLOOD PLAIN.")
1710 WRITE(5,400)
1720 400FORMAT("THE TOTAL REPLACEMENT COST OF ALL BUILDINGS IN THE FLOOD ")
1725 TOTCOST=TCOST*1000
1730 WRITE(5,401) TOTCOST
1740 401FORMAT("PLAIN IS $",F11.2," AND THE AVERAGE ANNUAL EXPECTED VALUE")
1745 EXVAL=SUMCOST*1000
1750 WRITE(5,402) EXVAL
1760 402FORMAT("OF DAMAGE TO BUILDINGS IN THE FLOOD PLAIN IS $",F8.2,".")
1770 STOP
1780 END
```

APPENDIX D

FORTRAN PROGRAM "ANCOST"

```
CALL ATTACH(11,"BLDCSORT,R;",1,0,,)
CHARACTER NPRINT
NPRINT="YES"
WRITE(5,77)
77FORMAT(/////"                                   ANCOST"///)
WRITE(5,88)
88FORMAT("   THIS PROGRAM COMPUTES THE AVERAGE ANNUAL EIPECTED COST")
WRITE(5,89)
89FORMAT("OF DAMAGES WHICH WOULD OCCUR AT EACH 1 FT INTERVAL OF FLOOD")
WRITE(5,90)
90FORMAT("ELEVATION FROM 790 FT TO THE DESIRED MAXIMUM ELEVATION TO BE")
WRITE(5,91)
91FORMAT("CONSIDERED IN THE FLOOD PLAIN.")
WRITE(5,199)
199FORMAT(//"   AT EACH 1 FT INCREMENT OF ELEVATION, THE PROGRAM")
WRITE(5,200)
200FORMAT("PROVIDES THE ELEVATION AND THE PROBABILITY OF THAT FLOOD")
WRITE(5,201)
201FORMAT("ELEVATION OCCURRING."//)
WRITE(5,202)
202FORMAT("   THE PROGRAM LISTS EACH BUILDING AFFECTED BY THAT FLOOD;")
WRITE(5,204)
204FORMAT("AND IT COMPUTES AND DISPLAYS THE ESTIMATED DAMAGES DUE TO")
WRITE(5,206)
206FORMAT("FLOODING AT THAT ELEVATION FOR EACH BUILDING.  THEN IT")
WRITE(5,207)
207FORMAT("SUMS THOSE VALUES FOR ALL AFFECTED BUILDINGS TO PROVIDE")
WRITE(5,208)
208FORMAT("THE NUMBER OF BUILDINGS AFFECTED, THE ESTIMATED DAMAGE,")
WRITE(5,210)
210FORMAT("AND THE EXPECTED VALUE OF DAMAGE FOR ALL BUILDINGS AT")
WRITE(5,209)
209FORMAT("THAT ELEVATION."//)
WRITE(5,211)
211FORMAT("   FINALLY, THE PROGRAM SUMS THE VALUES OVER ALL ELEVATIONS")
WRITE(5,212)
212FORMAT("TO PROVIDE A SUMMARY OF THE IMPACT OF FLOODING WITHIN THE")
WRITE(5,213)
213FORMAT("REQUESTED RANGE OF ELEVATIONS.")
DO 4 K=1,10
WRITE(5,230)
230FORMAT(//"ENTER THE DESIRED MAXIMUM ELEVATION.")
READ(6,99) N
99FORMAT(V)
IF(N.LT.790) GO TO 5
WRITE(5,231)
231FORMAT("DO YOU WANT THE DAMAGES DISPLAYED FOR EACH BUILDING?")
READ(6,101) NOTION
101FORMAT(A3)
```

```
WRITE(5,240)
240FORMAT("WHAT FACTOR TIMES THE REPLACEMENT COST IS THE MAIIMUM")
WRITE(5,241)
241FORMAT("EXPECTED DAMAGE TO THE BUILDING?")
READ(6,99) FACTOR,FACTA,FACTB
SCOST=0
DO 15 I=800,N
PROBINT=1/(10**((I-789.652)/10.9009))
PROBNIT=1/(10**((I+1-789.652)/10.9009))
PROB=PROBINT-PROBNIT
WRITE(5,214) I,PROB
214FORMAT(//"ELEV. ",I3,"     PROB. ",F6.4)
220FORMAT("NBLDC            COST")
SUMCOST=0
SDCOST=0
TCOST=0
NBLD=0
DO 13 J=1,77
READ(11,100) LN,NBLDG,ELEV,NSQFT,NCONST,EAVEHT,REPCOST,NUSE
100FORMAT(I4,1X,I4,1X,F5.1,1X,I6,I2,1X,F4.1,1X,F6.0,1X,I3)
IF(ELEV.GT.I) GO TO 17
HTAFLR=I-ELEV
RC=REPCOST*FACTOR
DAMAGE=RC*(HTAFLR/EAVEHT)
IF(HTAFLR.LT.(EAVEHT/2)) DAMAGE=(HTAFLR/(EAVEHT/2))*RC*FACTA
ELEVEL=(EAVEHT-HTAFLR)/(EAVEHT/2)
IF(HTAFLR.GE.(EAVEHT/2)) DAMAGE=RC-(ELEVEL*RC*FACTB)
IF(HTAFLR.GE.EAVEHT) DAMAGE=RC
ESTCOST=DAMAGE*PROB
COST=ESTCOST*1000
DCOST=DAMAGE*1000
299FORMAT(1X,I4,11X,F9.2)
NBLD=NBLD+1
TCOST=TCOST+REPCOST
TOTCOST=TCOST*1000
SUMCOST=SUMCOST+COST
SDCOST=SDCOST+DCOST
IF(NOTION.NE.NPRINT) GO TO 9
IF(NBLD.EQ.1) GO TO 7
GO TO 8
7 WRITE(5,220)
8 WRITE(5,299) NBLDG,DCOST
9 CONTINUE
13 CONTINUE
17 CONTINUE
REWIND 11
WRITE(5,399) NBLD,SDCOST,SUMCOST
399FORMAT(1H ,I4," BLDGS., DAMAGE= ",F11.2," EXPECTED COST= ",F9.2)
SCOST=SCOST+SUMCOST
15 CONTINUE
```

```
WRITE(5,499)
499FORMAT(//"   FLOODING AT THE REQUESTED RANGE OF ELEVATIONS WOULD")
WRITE(5,500) NBLD
500FORMAT("AFFECT ",I2," BUILDINGS.  THE TOTAL REPLACEMENT COST OF")
WRITE(5,501) TOTCOST
501FORMAT("THOSE BUILDINGS IS $",F9.0," AND THE AVERAGE ANNUAL EXPECTED")
WRITE(5,502) SCOST
502FORMAT("VALUE OF FLOODING UP TO THIS ELEVATION IS $",F9.2)
4 CONTINUE
5 CONTINUE
STOP
END
```

SELECTED BIBLIOGRAPHY

A. REFERENCES CITED

1. Beard, Leo R., and others. Hydrological Engineering Methods and Water Resources Development. Volume 1. Requirements and General Procedures. Davis CA: U.S. Army Corps of Engineers Hydrological Engineering Center, 1971.

2. Berger Associates. Potential Flood Damage Study for Dry Creek Goodlettsville, Tennessee. Columbus OH: Department of Army, Corps of Engineers, Nashville District, August 1978.

3. Bidgood, Lieutenant Colonel C., USA. District Engineer, Corps of Engineers, U.S. Army/OVLGD. Letter, subject: Frequency of Utilization of Storage, Huffman Reservoir, to Command General Wright-Patterson AFB OH, 28 July 1952.

4. Building Construction Cost Data 1977, 37th Edition. Duxbury MA: Robert S. Means Company, 1978.

5. Coretes-Comerer, Nhora, ed. "The Extraordinary Genius of Arthur E. Morgan," Civil Engineering, October 1977, pp. 114-117.

6. Department of the Air Force, Headquarters Air Force Systems Command. Cost Estimating Procedures. AFSCM 173-1. Andrews AFB, Washington DC: 17 April 1972.

7. Emory, William C. Business Research Methods. Homewood IL: Richard D. Irwin, Inc., 1976.

8. Grant, Eugene T., and W. Grant Ireson. Principles of Engineering Economy. 5th ed. New York: The Ronald Press Company, 1970.

9. Hoeffner, Otto. Chief, Environmental Planning Section, Base Civil Engineer, Wright-Patterson AFB OH. Personal interviews, November 1978.

10. Hollander, Gerald M. "Ingredients for Accurate Construction Cost Estimating," Actual Specifying Engineer, June 26, 1974, pp. 42-51.

11. Huffman Reserve brochure published for the Dayton-Montgomery County Park District by Allied Printing, Dayton, OH, 1975.

12. INTASA. Preliminary Review and Analysis of Flood Control Project Evaluation Procedures. U.S. Army Engineer Institute for Water Resources, IWR Report 70-3, Alexandria VA, September 1970.

13. Kennedy, James F. G., Squadron Leader, RAAF, and Major David R. Thomas, USAF. "Determination of Flood Stage-Damage Relationships at Wright-Patterson AFB." Unpublished research report, School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, May 1978.

14. Linsley, Ray K., and Joseph B. Franzini. Water Resources Engineering. New York: McGraw-Hill Book Company, 1964.

15. Merritt, Frederick S., ed. Standard Handbook for Civil Engineers. New York: McGraw-Hill Book Company, 1968.

16. Miami Conservancy District. Huffman Retarding Basin Operation, 1922-1977. Dayton, Ohio, 1978.

17. Molnar, John. "Cost Estimating Techniques," Actual Specifying Engineer, July 10, 1974, pp. 40-42.

18. Morgan, Arthur E. Report of the Chief Engineer of the Miami Conservancy District. Dayton: 1916.

19. ________. The Miami Conservancy District, New York: McGraw-Hill Book Company, 1951.

20. Moser, David A., and Charles A. Berry. Empirical Investigation of the Existence and Magnitude of a Commercial and Industrial Affluence Factor. U.S. Army Engineer Division, Ohio River, Cincinnati OH. IWR Reserach Report 77-R3, September 1977.

21. Nie, Norman H. and others. SPSS: Statistical Package for Social Sciences. New York: McGraw-Hill Book Company, 1975.

22. Office of the Chief of Engineers, Department of the Army. Alabama-Coosa Basin Report to the President's Water Resources Policy Commission, Washington, D.C., 1950.

23. Paxton, Albert S. National Repair and Remodeling Estimator: 1977. Solana Beach CA: Craftsman Book Company, 1976.

24. Pickels, George W. Drainage and Flood-Control Engineering. New York: McGraw-Hill Book Company, 1941.

25. Rietman, Harry P. Associate Director, Directorate of Engineering and Services, HQ USAF/PRE. Letter subject: Recently Completed and Planned Construction Affecting Floodplains and Wetlands, to HQ AFLC/DE, 5 May 1978.

26. Upper Colorado Region State-Federal Inter-Agency Group, Pacific Southwest Inter-Agency Committee, Water Resources Council. Upper Colorado Region Comprehensive Framework Study, Appendix IX, Flood Control, June 1971.

27. U.S. Army Corps of Engineers. Proceedings of a Seminar of Computer Applications in Hydrology. Davis CA: The Hydrologic Engineering Center, February, 1971.

28. U.S. Army Engineer Division, Ohio River, Cincinnati, Ohio. Ohio River Basin Comprehensive Survey, Volume XIV, Appendix M, Flood Control, December 1967.

29. U.S. Department of the Army. U.S. Army Engineering Manual for Military Construction, Damage and Erosion Control. Part XIII as condensed in the U.S. Army Engineer School correspondence course text entitled, "Drainage, Engineer Subcourse 359," Ft. Belvoir VA, 1955.

30. U.S. Department of Housing and Urban Development. Reprinted from Federal Register, "Executive Order 11988" Vol. 42, No. 101 (May 25, 1977).

31. "Warranty Deed" recorded in Volume 920, page 443 of Deed Records of Montgomery County, Ohio, 1922.

32. Wonnacott, Thomas H. and Ronald J. Wonnacott. Introductory Statistics for Business and Economics. Santa Barbara CA: John Wiley and Sons, 1977.

33. Woodard, Sherman M. Hydraulics of the Miami Flood Control Project, MCD Technical Reports Part VII, Dayton, Ohio, 1920.

34. Wright-Patterson AFB, Minutes of Plan Board Meeting, 23 October 1952. Wright-Patterson AFB, OH.

B. RELATED SOURCES

Arizona University. A Methodology for Planning Land Use and Engineerng Alternatives for Flood Plain Management System Model, U.S. Army Engineer Institute for Water Resources (Army), August 1973.

DeGarmo, E. Paul, and John R. Canada, Engineering Economy. 5th ed. New York: MacMillan Publishing Company, Inc., 1973.

Economic Research Service, United States Department of Agriculture, The Relationships Between Land Values and Flood Risk in the Wabash River Basin a Report Submitted to the U.S. Army Engineer Institute for Water Resources. IWR Report 69-4, December 1969.

Freund, John E. Mathematical Statistics. Englewood Cliffs NJ: Prentice-Hall, Inc., 1962.

INSTASA. A Computer Simulation Model for Flood Plain Development Part II: Model Description and Applications, Institute for Water Resources, Department of the Army Corps of Engineers. IWR Report 73-1, November 1972.

Menderhall, William and Richard L. Scheaffer. Mathematical Statistics with Applications. North Scituate MA: Duxbury Press, 1973.

University of Chicago, Center for Urban Studies, Community Goals--Management Opportunities: An Approach to Flood Plain Management. U.S. Army Engineer Institute for Water Resources, IWR Report 70-2; Alexandria VA. May 1970.

U.S. Army Corps of Engineers. Guidance for Reducing Flood Damages. Springfield VA: January 1968.

________. Baltimore District. Cost Report on Non-Structural Flood Damage Reduction Measures for Residential Buildings Within the Baltimore District. Ft. Belvoir VA: IWR Pamphlet No. 4, Army Corps of Engineers Institute for Water and Water Resources, July 1977.

Wright-Patterson AFB. 2750 ABW Oplan 355-1. Appendix 2, Annex D, "Flood Control," Wright-Patterson AFB OH, amendment 2, July 1978.